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IRON

ITS

HISTORY, PROPERTIES, AND PROCESSES OF MANUFACTURE

BY

Sir WILLIAM, bart. FAIRBAIRN, C.E., LL.D., F.R.S., F.G.S.

CORRESPONDING MEMBER OF THE NATIONAL INSTITUTE OF FRANCE, AND OF THE ROYAL ACADEMY OF TURIN; CHEVALIER OF THE LEGION OF HONOUR, ETC. ETC.

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PREFACE.

DURING the publication of the eighth edition of the "Encyclopædia Britannica," I was suddenly called upon to write an article on the Iron Manufacture; and it was intimated that the publication was so far advanced that I could not be allowed more than a few weeks for the purpose. Thus placed, with other professional engagements to attend to, I had not only to work early and late, but I had to hurry through the work, in order to prevent delay and disappointment in the appearance of the volume. It was under these conditions the article was written, and they must be my apology for the imperfections it contained.

The Publishers, aware of these circumstances, have very handsomely come forward with an offer to print the article in a more complete state, and in a separate volume; and, having made considerable additions, I again submit it in a form which, I trust, may be more

useful than when it appeared in the publication in question.

A very slight acquaintance with natural science will exhibit the wisdom of a bountiful Creator in the wide diffusion and abundant supply of iron and coal, two of the greatest boons conferred upon the human race. If we refer to the history of the past, and trace the change from barbarism to a state of intellectual culture, we see at every step the contrivances and appliances of the "cunning workers in iron." These have always been the associates of mental progress, and the providers for the wants and necessities of our social existence.

In this treatise I have endeavoured, in a concise history, to trace the progress of the iron manufacture from its earliest beginnings down to the present time, and the various improvements which have been effected in the reduction of the ores, and the subsequent manipulation of the crude iron. I have also given analyses of the ores and fuel, so far as they bear on the results of the different processes of manufacture; this will show the reader how much we owe to chemical science, and to the distinguished men who have laboured so industriously and successfully in this important field of research.

The description of the furnaces, machinery, &c., employed in the production of iron, I have, from my own

experience, been enabled to trace from its almost primitive condition to its present high state of improvement. There is still much to be done; and now that the subject of reduction, conversion, rolling, forging, &c., are so well understood, we may reasonably look forward to much greater improvements, combined probably with more extended chemical researches, calculated to establish a new era in the history of the manufacture of iron and steel.

In connection with the history of iron and its manufacture, I might have treated on a question of equal importance, namely, Iron Appliances; but this is a subject of such magnitude as to require a distinct treatise. I have already partially treated of it in other publications, and any notice in this place could only disappoint the reader by its incompleteness.

On the subject of statistics, I am fortunate in having before me the returns of Mr Robert Hunt, F.R.S., of the School of Mines, published in the "Memoirs of the Geological Survey of Great Britain." To Mr Bessemer I owe the very complete and interesting details of the process he has introduced, along with accurate drawings of the best forms of apparatus, embodying the results of his laborious and important investigations down to the most recent date. To Mr Mushet, Mr Frith, and Mr Clay, I am also

indebted for information regarding the most recent improvements and discoveries effected in different processes, and to my own secretary, Mr Unwin, for the able assistance I always receive from him in the execution and progress of researches in practical science.

ERRATUM.

At page 39, lines 4 and 5 from bottom, transpose the words "red-short" and "cold-short."

CONTENTS.

INTRODUCTION.

IRON, on account of its abundance, working qualities, and tenacity, is probably the most useful and valuable of metals. According to Dr Ure, "it is capable of being cast into moulds of any form, of being drawn into wire of any desired length or fineness, of being extended into plates or sheets, of being bent in every direction, of being sharpened, or hardened, or softened at pleasure. Iron accommodates itself to all our wants and desires, and even to our caprices; it is equally serviceable to the arts, the sciences, to agriculture, and war; the same ore furnishes the sword, the ploughshare, the scythe, the pruning-hook, the needle, the graver, the spring of a watch or of a carriage, the chisel, the chain, the anchor, the compass, the cannon, and the bomb. It is a medicine of much virtue, and the only metal friendly to the human frame." In its primitive position, it is commingled with the earth's strata in bountiful profusion; it is found in various combinations and conditions in every formation,

and it is a constituent element of both animals and vegetables.

In treating of the manufacture, properties, and production of this most important material, it will conduce to perspicuity to arrange the subject under twelve distinct heads, viz.—I. The History; II. The Ores; III. The Fuel; IV. Smelting by the Hot and Cold Blast; V. Manufacture of Wrought-Iron; VI. The Mechanical Operations of the Cast-Iron Manufacture; VII. The Forge; VIII. Mr Bessemer's Process; IX. The Manufacture of Steel; X. The Mechanical Properties of Cast and Wrought Iron and Steel; XI. The Chemical Constituents of Iron in its Manufactured States; XII. Statistics of the Iron Trade.

CHAPTER I.

THE HISTORY OF THE IRON MANUFACTURE.

MALLEABLE iron appears to have been known from a remote antiquity. Its obvious utility and great superiority over the softer metals, then commonly used, combined with the expense of its reduction, caused it to be highly prized, though the extreme difficulty of working it by the rude methods then employed greatly restricted its application.* There are notices in Homer and Hesiod of the arts of reducing and forging iron, but cast-iron was then unknown, an imperfectly malleable iron being produced at once from the ores in the furnace. It is probable that the Greeks obtained most of their iron through the Phœnicians from the shores of the Black Sea and from Laconia.

It would be interesting to trace the gradual advances which have been made in the reduction of iron from its discovery to the present time; to inquire into the circumstances which led to the successive changes in the processes, and into the principle on which those changes were founded; to examine into the differences in the products which from time to time ensued, and to notice

* This is shewn by the epithet πολύκμητος (much-wrought), applied to it by Homer (*Iliad*, vi. 48).

the influence of these conditions on the extent and progress of the manufacture. Our knowledge of these changes, however, is scanty and imperfect, and we can only conjecture what was probably its early progress.

The furnaces which were first employed for smelting iron were probably similar to those now called *air-bloomeries.* They were probably simple conical structures, with small openings below for the admission of air, and a large one above for the escape of the products of combustion, and would be erected on high grounds in order that the wind might assist combustion. The fire being kindled, successive layers of ore and charcoal would be placed in it, and the heat regulated by opening or closing the apertures below.

The process of reduction would consist of the deoxidation of the ore and the cementation of the metal by long continued heat. The temperature would never rise sufficiently high to fuse the ore, and the product would therefore be an imperfectly malleable iron, mixed with scoriæ and unreduced oxide. It would then be brought under the hammer, and fashioned into a rude bloom, during which process it would be freed from the greater portion of its earthy impurities.

By such a process as this the Romans probably worked the iron ores of our own island; scoriæ, the refuse of ancient bloomeries, occur in various localities, in some cases identified with that people by the coincident remains of altars dedicated to the god who presided over iron. Mungo Park saw a rude furnace of this kind used by the Africans, and, indeed, with some modifications, it is still retained in Spain, along the coasts of the Mediterranean,

and in some parts of America, where rich specular or magnetic ores are worked.

The advantages of an artificial blast would soon become manifest, and a pair of bellows, or a cylinder and piston, would soon be applied to the simple construction mentioned above. Homer represents Hephæstus as throwing the materials from which the shield of Achilles was to be forged into a furnace urged by twenty pairs of bellows (φῦσαι). The inhabitants of Madagascar smelt iron in much the same way, their blowing apparatus, however, consisting of hollow trunks of trees, with loosely fitting pistons worked by hand.

The furnace corresponds to the *blast*-bloomery, and has by successive improvements developed into the blast furnace, now almost universally used, and into the *Catalan forge*, still employed in some districts. The application of the blast would offer considerable advantages; it would obviate the necessity of an elevated site, place the temperature more immediately under the direction of the smelter, and render the whole process more regular and certain. The method of reduction remained the same as before, but the product would differ considerably, for whenever the blast was sufficiently powerful, the iron would be *fused*, a partial carburation would take place, and the resulting metal would be a species of steel, utterly useless to the workmen of those days; hence, it seems necessary to infer, that a rude process of refining was invented: the metal being again heated with charcoal, and the blast directed over its surface, the carbon would be burnt out, and the iron become tough and malleable. The processes might perhaps form two successive stages of

one operation, as at present practised with the Catalan forge.

The increasing demand for iron, and the progress of internal communication, would lead the smelter to increase the size and height of his bloomery, and this probably would lead to a very unexpected result. The greater length through which the ore had to descend would prolong its contact with the charcoal, and a higher state of carburation would ensue, the product being cast-iron—a compound till then perhaps unknown.

From the time that cast-iron became the product of the smelting furnace, the refining would be made a separate process, requiring a separate furnace and machinery. It would soon be found also, that, as the furnace increased in height, the pressure of the superincumbent mass would render the materials so dense as to retard the ascent of the blast, and thus cause it to become soft and inefficient; hence the internal buttresses called *boshes* were first introduced to support the weight of the charge, relieving the central parts from the pressure, and permitting the free ascent of the blast. Whilst the good quality of the iron and the regularity of the process were thus ensured, increase of quantity was the result of improvements in the blowing apparatus, which was now enlarged and worked by water-power. With these modifications, the furnace was the same essentially as the blast-furnace now employed, though not so large; indeed, until the introduction of coke at a much later period, the blast-furnace seldom exceeded 15 feet in height by 6 at the widest diameter. The more perfect operation of the blast-furnace allowed the reduction of the heaps of scoriæ, which

had been gradually accumulating during the period that the blast-bloomeries had been in operation, and which contained 30 to 40 per cent. of iron. A new species of property was thus created—extensive proprietorships of Danish and Roman cinders were formed. Large deposits of scoriæ, which for ages had lain concealed beneath forests of decayed oak, were dug up; and in Dean Forest it is computed that twenty furnaces, for a period of upwards of 300 years, were supplied chiefly with the bloomery cinders as a substitute for iron ore.

At what period the complete transformation of the blast-bloomery into the blast-furnace was effected, it is impossible to say. It was probably in the early part of the sixteenth century, as we find that in the seventeenth the art of casting had arrived at a considerable degree of perfection, and in the reign of Elizabeth there was a considerable export trade of cast-iron ordnance to the Continent. In the forest of Dean are the remains of two blast-furnaces which formerly belonged to the kings of England; but they have been out of blast since the commencement of the struggle between Charles I. and his Parliament. Calculating from the quantity of scoriæ accumulated in their immediate neighbourhood, which appears to have lain undisturbed for the last two centuries, Mr Mushet has attempted to deduce the period of their erection, which he conceives to have been about the year 1550, in the time of Edward VI.

Up to this period wood charcoal was the only material employed in smelting operations; but the wants of a constantly increasing population, not less than the great consumption of the blast-furnaces themselves, created a

scarcity of this essential material, and gave a check to the manufacture. To such an extent had the wood been destroyed, that the cutting down of timber for the use of the iron-works was prohibited by special enactments; and the forests of Sussex alone appear to have been exempt from the general decree of conservation. The number of furnaces in blast decreased three-fourths, and the annual production, which but a short time before is said to have been 180,000 tons, was in 1740 reduced to only 17,350 tons.

James I. granted patents to ironmasters in various parts of the kingdom for using pit-coal in the manufacture of iron. The obstacles to its introduction, however, were numerous, and not easily overcome. Lord Dudley appears to have been the first successful patentee connected with the iron manufacture; and his patent, obtained in 1621, related to "the misterie and arte of melting iron ewre, and of making the same into cast workes or barrs, with sea coles or pit coles in furnaces, with bellowes." Lord Dudley was only able to make iron at the rate of three tons a week; but so important did his patent appear, that it was specially exempted from the operation of James I.'s statute abolishing the grants of monopolies. The comparatively incombustible nature of coke, and its feebler chemical affinities, rendered a more powerful blast and a longer subjection to the heat indispensable to its succcessful adoption. Ignorance of the causes of failure operated long and seriously, but all difficulties were at length surmounted. An enlargement of the height of the furnace prolonged the contact of the ore and coke, and at last the employment of the steam-engine

and improved blowing apparatus rendered the blast much more powerful and regular, and gave that impetus to the manufacture which has caused Great Britain to take the first rank in this branch of industry.

The first great improvement on the blowing apparatus was the substitution of large cylinders, with closely fitting pistons, for the bellows. The earliest of any magnitude were probably those erected by Smeaton at the Carron Iron-Works, in 1760.

In 1783–4, Mr Cort of Gosport introduced the processes of puddling and rolling, two of the most important inventions connected with the production of iron since the employment of the blast furnace.

Mr Cort obtained two patents, the first in 1783, respecting "a peculiar method and process of preparing, welding, and working various sorts of iron, and of reducing the same into *uses* by machinery, and a furnace and other apparatus adapted to the same purpose." In February 1784 he obtained a second, comprising "shingling, welding, and manufacturing iron and steel into bars, plates, rods, and otherwise, of purer quality, in larger quantities, by a more effectual application of fires and machinery, and with a greater yield, than any method before put in practice." His first patent comprises methods of faggoting bars for various kinds of uses, the hammer and anvil being employed, and the faggots brought to a welding heat in a balling furnace instead of one with a blast. By passing faggots through rollers, "all the earthy particles are pressed out," and the iron compressed into a tough and fibrous state. Bars of bad quality may be improved by rolling, and several bars rolled together become per-

fectly united. He points out that iron plates may be made in the same manner. He shows how the shape and dimensions of the plates and bars may be determined by collars and grooves in the rollers. In this patent we see, therefore, he has devoloped his system of faggoting and heating scraps and bars, and welding them into a mass, and compressing them into form by means of rollers and hammers. And the introduction of rollers in this process was a step in discovery we owe to him. There was still wanting a process for the production in this country in large quantities of the wrought iron itself. This he provided in his second patent. He introduced a reverberatory furnace heated by coal, and with a concave bottom into which the fluid metal is run from the smelting furnace; and he showed how by a process of puddling, while exposed to the oxidising current of flame and air, the cast metal could be rendered malleable. He describes in his patent the stirring of the metal till ebullition ceases, and its collection as it becomes less fusible into blooms, the hammering of these to get rid of the slag, and their reduction to a marketable shape by the processes described in his previous patent. It would be a difficult task to enumerate all the services rendered by Mr Cort to the iron industry of this country, or sufficiently to express our sympathy with the relatives and descendants of a man to whose mechanical inventions we owe so much of our national greatness. It is, perhaps, not generally known that Mr Henry Cort expended a fortune of upwards of L.20,000 in perfecting his inventions for puddling iron, and rolling it into bars and plates; that he was robbed of the fruit of his discoveries by the villany

of officials in a high department of the Government, and that he was ultimately left to starve by the apathy and selfishness of an ungrateful country. When these facts are known, and it has been ascertained that Mr Henry Cort's inventions have conferred an amount of wealth on the country equivalent to *six hundred millions sterling*, and have given employment to *six hundred thousand* of the working population of our land for the last three or four generations, we are surely justified in referring to services of such vast importance, and in advocating the principle that such substantial proofs of the nation's gratitude should be afforded to rescue from penury and want the descendants of such a benefactor.

About this time the steam-engine of James Watt came into use, and along with it commenced a new era in the history of the iron trade and every other branch of industry. Its immense power, economy, and convenience of application, brought it at once into general use. It was soon applied to pumping, blowing, and rolling; it enabled mines to be sunk to a greater depth; refractory ores to be reduced with facility; and the processes of rolling, forging, &c., to be effected with a rapidity previously unknown in this or any other country.

Of late years, Scotland has made considerable progress in the iron manufacture. The introduction of railway communication, and the invention of the hot-blast, have given a stimulus to the trade which has raised Glasgow and its vicinity into importance as an iron district; and few towns possess greater facilities for the sale of their produce than this central depot of the mineral treasures of the country by which it is surrounded.

The hot-blast process, for which a patent was taken out by Mr Neilson in 1824, has effected an entire revolution in the iron industry of Great Britain, and forms the last era in the history of this material. His patent consists in the improved application of air to produce heat in forges and furnaces where bellows or other blowing apparatus are required. The blast produced in the ordinary way is heated in a closed air-vessel, before being conducted into the furnace, to a considerable temperature. The air-vessel was heated by a fire distinct from that to which the blast was applied. The manner, however, of heating the air-vessel is immaterial to the effect if it be kept at a proper temperature. This simple but effective invention has given such facilities for the reduction of refractory ores, that between three and four times the quantity of iron can be produced weekly, with an expenditure of little more than one-third of the fuel; and, moreover, the coal does not in most cases require to be coked, or the ores to be calcined.

The more important of the changes of the iron manufacture since Neilson's time have been, to sum them up very briefly, the direct production of wrought iron from rich ores in a reverberatory furnace accomplished by Mr Clay in 1840; the use of oxide of manganese in the production of steel, attempted by Reynolds in 1799, and by many others since, including Heath and Vickers in 1839, Schafhautl in 1835, Mr Leachman in 1853, Mr Brooman in 1854, Mr Crowley in 1855, and Mr Mushet in 1856; in most cases other materials, as chloride of sodium, ferrocyanide of potassium, and carbonate of lime, in various proportions, being also employed.

The introduction of anthracite, stone coal, or culm, in smelting, is due chiefly to Mr Crane in 1836, and Mr Budd in 1842, a blast of high pressure being employed, heated to a high temperature. The application of peat has also been attended with success, very good qualities of iron being produced with it on the Continent, and to a small extent in Ireland. Plans have also been introduced for the reduction, and for puddling iron, by the gaseous product of combustion alone, the ores not being allowed to come in contact with the mineral constituents of the fuel. In the case of the processes of puddling and refining, plans of this kind have for some time been in use in Silesia; and more recently Dr Gurlt has proposed the reduction of the metal in the same way. Mr Nasmyth made one of the most important additions to the machinery of the iron trade by the invention of the steam hammer in 1842: this most powerful and ingenious tool has received of late many modifications in the hands of Mr Condie, Mr Naylor, Mr Wilson, and others.

The utilisation of the waste or gaseous products was attempted by Teague in 1832, and Meckenheim in 1842, and has been the subject of many patents. Steam has been employed in puddling by Guest and Evans in 1840, Nasmyth in 1854, Martien and Bessemer in 1855, and Talabot in 1857. Messrs Lea and Hunt would use the products of the coke furnace as a source of heat in puddling, and Mr Mickle endeavoured to collect the gases and employ them in smelting. Captain Uchatius (1855) has successfully converted cast metal into steel by granulating it in water, and decarbonising it by fusion with spathose ore. Cyanogen has been used in the production

of steel by cementation by Mr Brooman and Mr Newton, and Mr Bessemer has introduced an entirely new process for obtaining both wrought iron and steel by decarbonising it in a fluid state, by passing through it copious currents of air and steam. Other manufacturers are producing a homogeneous and malleable steel in the form of plates and bars by a modification of the puddling process.

In conclusion, we may add that there appear to have been five distinct epochs in the history of the iron trade.

The *first* dating from the employment of an artificial blast to accelerate combustion.

The *second* marked by the employment of coke for reduction, about the year 1750.

The *third* dating from the introduction of the steam-engine; and on account of the facilities which that invention has given for raising the ores, pumping the mines, supplying the furnace with a copious and regular blast, and moving the powerful forge and rolling machinery, we may safely attribute this era to the genius of James Watt.

The *fourth* epoch is indicated by the introduction of the system of puddling and rolling, very soon after the employment of the steam-engine.

The *fifth*, and last—though not the least important epoch in the history of this manufacture—is marked by the application of the hot-blast—an invention which has increased the production of iron fourfold, and has enabled the ironmaster to smelt otherwise useless and unreducible ores; it has abolished the processes of coking and roasting, and has given facilities for a large and rapid production, far beyond the most sanguine anticipations of its inventor. Manufacturers, taking advantage of so powerful an agent,

have not hesitated to reduce improper materials, such as cinder-heaps and impure ores; and by unduly hastening the process, and attending to quantity more than to quality, have produced an inferior description of iron, that has brought the invention into unmerited obloquy.

CHAPTER II.

THE ORES.

THE ores of iron are found in profuse abundance in every latitude, embedded in or stratified with every formation. They occur both crystallized, massive, and arenaceous, lying deep in strata of vast extent, filling veins and faults in other rocks, and scattered over the surface of the ground. Sometimes, but rarely, found native; usually as oxides, sulphurets, or carbonates, more or less mingled with other substances. Of these ores there are perhaps twenty varieties, many of which are, however, rare; others are combined with substances which unfit them for the manufacture of iron, so that the remainder may be classed under the following general heads; their composition, however, varies greatly:—

1. The magnetic oxides, in which the iron occurs, as $Fe_3\,O_4$ or $Fe_2\,O_3 + Fe\,O$, containing 72·4 per cent. of iron to 27·6 of oxygen, supposing it pure. This is the purest ore which is worked; the best Swedish metal is manufactured from it. It is found in primitive rocks, and is widely diffused over the globe. The beds of ore at Arendal, Täberg, Kurunavara, &c., consist of this oxide in a massive state.

2. Specular iron ore and red hæmatite, peroxide of

iron, $Fe_2 O_3$, containing 70 per cent. of iron to 30 of oxygen, when pure. This is a rich and valuable ore, and has been worked from a remote antiquity in Elba and Spain; it occurs in the caves of Etna and Vesuvius, as lustrous specular iron. Red hæmatite occurs in botyroidal radiating masses in Cumberland, Saxony, Bohemia, and the Hartz, and in America abundantly.

3. Brown hæmatite, or hydrated peroxide of iron, $2 Fe_2 O_3 + 3 HO$. Brown hæmatite occurs massive, mammillary, and stalactitic. Decomposed earthy varieties are known as ochrey brown iron ore. Brown and yellow clay ironstone is mingled oxide and clay. Bog ore is found in beds in Bohemia, Poland, and Russia, and usually contains phosphates.

4. Carbonate of iron, or spathic iron ore, $Fe O, CO_2$. This ore occurs mixed with large quantities of argillaceous, carbonaceous, and siliceous substances, forming the large deposits of spathic iron ore, clay-ironstone, and blackbands, from which most of the iron of this country is obtained. These strata are generally found in close proximity to the Coal Measures. In Styria and Carinthia it forms extensive tracts in gneiss. The spathic ores, and also the siliceous ores, are comparatively pure. The clay-ironstones, and still more the blackbands, are much poorer in iron.

5. In addition to the above, we may mention that native iron has been obtained in masses, usually of meteoric origin, in various parts of the world, and in this case contains from 1 to 20 per cent. of nickel. At Yale College, in America, a meteorolite is preserved, weighing 1635 lbs.; length, 3 feet 4 inches; breadth, 2 feet 4 inches; height, 1 foot 4 inches. It contained 90 to

93 per cent. of iron, and 8·8 to 9·6 per cent. of nickel. Pallas discovered a meteorolite in Siberia weighing 1600 lbs.; and still larger masses have been found in South America. At Canaan, Connecticut (*American Journal of Science*, xii. 154, and (2) v. 292), a mass, supposed to be of terrestrial origin, was found, in the form of a plate or vein two inches thick, attached to a mass of mica slate rock. Iron pyrites ($Fe\ S_2$) occurs abundantly in rocks of all ages, in cubes, nodules, and veins. It is used in the manufacture of sulphur, sulphuric acid, and sulphate of iron; but its composition renders it unavailable for the production of iron itself. The arsenical, chromic, and titaniferous ores, and the borate, columbate, tungstate, phosphate, &c. of iron, do not need a more lengthened notice in this treatise.

All the above ores are more or less mixed with silica, alumina, oxide of manganese, &c.; and it may not be uninteresting to glance at their chemical composition and their geographical distribution in Europe and America.

England possesses peculiar and remarkable advantages for the manufacture of iron. The ores are found in exhaustless abundance, usually interstratified with the coal necessary for their reduction, and in close proximity to the Mountain Limestone, which is used as a flux. In few countries do these three essential materials occur in such abundance, or so near together as to give the necessary facilities for a large and profitable production.

In the North of England the ores of iron occur, geologically speaking, in the three formations known as the Carboniferous Limestone, the Coal Measures, and the Lias. The following details are chiefly from the "Memoirs of the Geological Survey of Great Britain:"—

THE ORES OF THE CARBONIFEROUS LIMESTONE.

In this formation, consisting in the North of England of strata of limestone, gritstone, and shale, the argillaceous carbonate occurs in some of the bands of shale in strata like those more abundant in the Coal Measures. The hydrous sesquioxide, or brown hæmatite, appears in some instances also to form layers, although its mode of occurrence is at present more doubtful. A stratum of the carbonaceous blackband ore has been worked at Haydon Bridge. Some of the lead veins of the Alston district are charged with brown iron ore, and in other parts with the sparry carbonate, and in both cases have of late been successfully worked. The red hæmatite of Whitehaven occurs in the same Carboniferous Limestone near the outcrop of the slaty rocks on which that formation rests. This fine and pure ore occurs in magnificent beds, 15, 30, and even 60 feet in thickness, usually subterraneous, but occasionally at the surface. Very little of this is smelted on the spot, owing to the want of fuel—not more in 1857 than 56,511 tons; but in the same period 193,850 tons were shipped at Whitehaven, and 66,651 tons conveyed by railway, to Wales, Staffordshire, Scotland, Newcastle, &c. The hæmatite is also worked at Stainton, Lindale, Ricket Hills, Elliscales, and Mousell. At the Park and Roanhead Mines "you may proceed 400 to 500 feet in either direction in one solid mass of this valuable substance, and nothing has as yet been seen of the bottom of it."

In Wales, extensive deposits of hæmatite occur in Glamorganshire, in the upper beds of the Carboniferous Limestone; and of late these have been extensively worked.

THE IRONSTONES OF THE COAL MEASURES.

The ores in the Coal Measures consist almost exclusively of the argillaceous clay-ironstone in concretionary nodules. In the Yorkshire coalfield they are not plentiful, though a sufficiency is found to supply furnaces in which a peculiar bed of coal is employed, remarkably free from sulphur; and this, with studious care in the manufacture, results in the production of the fine qualities of iron known as Lowmoor, Bowling, Farnley, &c.

In the Derbyshire coalfield, of a total thickness of 1600 feet, the same valuable deposits of argillaceous ore occur in great abundance.

In Staffordshire, a portion of the coalfield has been so productively worked that the character of the country has been changed, and the number of smelting and puddling furnaces, the refuse of metallurgical operations, the coking heaps, all partaking of a general sooty character, have led to the application to this district of the epithet "the black country." "In no other coalfield of the United Kingdom," says Mr Beete Jukes, "is a thickness of 30 feet of coal to be found together; while in South Staffordshire twelve or thirteen beds of coal rest one upon the other, with but very slight *partings* of shale between them, making up often that thickness, and sometimes more. In the same way I believe the quantity of ironstone to be found in some parts of this district, within a vertical space of 100 or 150 yards, is greater than is known anywhere else."*

In Scotland, the blackband is the ore chiefly worked. It is an impure carbonate mingled with large quantities of bituminous and carbonaceous matter.

* Memoirs of the Geological Survey of Great Britain: "The Iron Ores of South Staffordshire." 1858.

THE ORES OF THE OOLITE.

Mr Edward Hull, in pursuing the Geological Survey, found considerable beds of siliceous iron ore belonging to the Lower Oolite, and a calcareous ore in the Upper Lias in the neighbourhoods of Banbury, Deddington, and Woodstock. The Woodstock ore, or Blenheim ore as Mr Hull has termed it, is almost identical in geological position and nature with the Cleveland ore of Yorkshire. It contains only 0·55 per cent. of phosphoric acid, and of metallic iron about 32 per cent.

In Northampton, a siliceous carbonate is being worked.

TABLE *exhibiting the Composition of Average Samples of British Iron Ores, from the "Memoirs of the Geological Survey."*

	II. Weardale Spathose Ore, Rispey.	III. Compact Red Hæmatite, Cleator Moor.	XXI. Cleveland Ore, chiefly Carbonate.	VII. White Bed Mine, Bierly, Yorkshire, Clay Ironstones.	XXVII. Gubbin Ironstone, Cannock, Dudley.	XXXI. Whitestone, Rough Hay Colliery, Darlaston, Clay Iron Ore.
Protoxide of iron .	49·47	...	39·92	35·38	45·86	33·92
Peroxide of iron .	...	95·16	3·60	1·20	...	2·77
Protoxide of manganese	2·42	0·24	0·95	0·94	0·96	0·77
Alumina . . .	trace.	...	7·86	0·80	0·42	0·67
Lime . . .	3·47	0·07	7·44	2·78	1·17	2·45
Magnesia . . .	3·15	...	3·82	2·22	1·65	4·11
Carbonic acid . .	37·71	...	22·85	25·41	31·02	26·89
Phosphoric acid .	trace.	trace.	1·86	0·48	0·21	0·35
Sulphuric acid . .	trace.	trace.	trace.	trace.	trace.	...
Silica . . .	0·91	...	7·12	...	0·42	0·09
Bisulphide of iron .	0·08	trace.	0·11	0·18	0·10	0·15
Organic matter . .	trace.	...	trace.	0·23	0·90	0·47
Potash . . .	...	...	0·27	...	...	0·14
Water in combination	...	...	2·97	1·11	1·08	0·98
Water, hygroscopic .	...	...	...	0·74		0·42
Insoluble residue, chiefly silica .	3·83	5·68	1·64	28·00	15·90	25·55
Iron, total amount,	38·56	66·60	33·62	28·76	35·99	28·87

The ores principally employed are the clay-ironstones

and carbonates of blackbands, which are found interstratified with the coal-fields of Ayrshire, Lanarkshire, Shropshire, South Wales, and other parts, and these vary in richness in different localities, according to position and the amount of silica, clay, and other foreign matter with which they are associated. The chemical composition of three varieties of the ore used in Lanarkshire is given by Dr Colquhoun, as follows:—

	No. 1.	No. 2.	No. 3.
Protoxide of iron	53·03	47·33	35·22
Carbonic acid	35·17	33·10	32·53
Silica	1·40	6·63	9·56
Alumina	0·63	4·30	5·34
Lime	3·33	2·00	8·62
Magnesia	1·77	2·20	5·19
Peroxide	0·23	0·33	1·16
Bituminous matter	3·03	1·70	2·13
Sulphur	0·00	0·22	0·62
Oxide of manganese	0·00	0·13	0·00
Moisture and loss	1·41	2·26	0·00
	100·00	100·00	100·37

The carbonic acid in the above ores may be partly combined with the lime as carbonate of lime, as well as with the protoxide of iron.

M. Berthier gives, according to Dr Ure, the following analyses of the English and Welsh ironstones of the Coal Measures:—

	Rich Welsh Ore.	Poor Welsh Ore.	Dudley Rich Ore or Gubbin.
Loss by ignition	30·00	27·00	31·00
Insoluble residuum	8·40	22·03	7·66
Peroxide of iron	60·00	42·66	58·33
Lime	0·00	6·00	2·66
	98·40	97·69	99·65

Calculating the amount of carbonate of iron and metallic iron indicated by the above analyses, we have—

Carbonate of iron . . .	88·77	65·09	85·20
Metallic iron	42·05	31·38	40·45

The richness of the above ironstones would be about 33 per cent. of iron. In the process of roasting, 28 per cent. of the ore is dissipated.

Mr Mitchell gives also the following assays of clay-ironstone and blackband ore, as under:—

	Clay Ironstone, Leitrim, Ireland.	Blackband Carbonate Ore.
Protoxide of iron	51·653	20·924
Peroxide of iron . . .	3·742	·741
Oxide of manganese . .	·976	1·742
Alumina	1·849	14·974
Magnesia	·284	·987
Lime	·410	·881
Potash	·274	trace.
Soda	·372	trace.
Sulphur	·214	·098
Phosphoric acid . . .	·284	·114
Carbonic acid	31·142	14·000
Silica	6·640	26·179
Carbonaceous matter . .	} 2·160	16·940
Loss		2·420
	100·000	100·000

In North Lancashire and Cumberland, the red hæmatite ores are now extensively worked, and great quantities are yearly shipped from Whitehaven, Ulverstone, &c., to Staffordshire, South Wales, and Scotland, for mixing with the poorer argillaceous and blackband ores. In Cumberland and North Lancashire, no less than 592,390

tons were raised in 1857 for this purpose, and the greater portion was exported from those districts.

In addition to these exports, about 25 to 30,000 tons are smelted by the hot blast at Cleator, in the neighbourhood of Whitehaven. It produces a strong and ductile iron, considered highly valuable for mixing with the weaker irons. These ores have been carefully analysed, and contain:—

Peroxide of iron	90·3
Silica	5·0
Alumina	3·0
Lime	trace.
Magnesia	trace.
Water	6·0
	104·3

Or about 62 per cent. of metallic iron.

In Ireland there are vast deposits of iron ore, of great richness, though as yet but little worked. Some of these, such as the ores worked at the Arigua Mines, and the Kidney ores of Balcarry Bay, yield nearly 70 per cent. of iron. If these mines were worked more extensively, and if peat fuel were used in the smelting operations, the iron would probably be of the very best quality, and might rival the famed Swedish charcoal metal. Of this there is now every reason to hope, as the establishment of railway communication, with almost every part of Ireland, will open out the immense peat bogs of that country, and facilitate the introduction of vegetable fuel for the reduction of the ores, and create a large and important addition to other branches of Irish industry. In a communication to the writer from Mr M'All, he

states:—"I have sent you samples of two kinds of iron ore; one is the red, the other the purple hæmatite. There are strata which are inexhaustible, and the ore can be raised and delivered at the furnace for less than a shilling a ton; the peat or vegetable carbon is equally cheap and abundant. Limestone of the purest quality is also close at hand, and can be delivered at the furnace at ninepence per ton. On account of the purity of these materials, iron of the greatest strength and ductility can be made, which, from its non-liability to corrode, would be admirably adapted for naval and marine purposes." Ireland is therefore, according to Mr M'All and others, in a condition to supply large quantities of excellent iron.

The Iron Ores of France.—France possesses an abundant supply of iron ore, but, on account of the scarcity of coal, the manufacture has been greatly restricted in extent. The introduction of railway communication is however rapidly removing this difficulty, and the operations of smelting are greatly on the increase. The railroad has enabled the French ironmaster to substitute coal for charcoal in the reduction of the iron ores, and in consequence an immense increase has taken place in the production of pig and manufactured iron. The ores are found in beds or strata in the Jura range; accumulated in kidney-shaped concretions in the fissures of the limestone; or dispersed over the surface of the ground; and but slightly covered with sand or clay.

They are found in the departments of the Yonne, the Meuse, and the Moselle, and indeed may be traced from the Pas de Calais on the north to the Jura on the south, indicating throughout an abundant and ample supply.

The present increased production of iron in France is chiefly due to the introduction of coal in smelting, but it may also be traced in some measure to the encouragement given by the Government to that branch of industry, and to the enterprise of such men as M. de Gallois and M. Dufrènoy, who have exerted themselves to extend its manufacture in that country. M. de Gallois resided in England for several years, immediately subsequent to the peace of 1815; and having obtained admission into the different iron-works here, he returned to France and established the works at St Etienne, now probably the largest and most extensive in that country.* The production of crude pig-iron in France is now little short of 1,000,000 tons annually; but the demand for railways, rolling-stock, bridges, iron ships, girders, and other constructions, is so great that large quantities of iron are still annually imported from this country.

The Iron Ores of Prussia.—Valuable deposits of the blackband and clay carbonate ores are found interstratified with the great coal-field of Ruhr; and the bog-iron and hæmatite ores are found in considerable profusion in Rhenish Prussia and other parts. In Upper Silesia, on the Vistula, and the Oder, large deposits of coal and iron are found in juxtaposition, and are worked to a considerable extent.

* The Universal Exhibition of last year (1855) fully justifies the remarks in reference to the great increase of the iron trade of France. Any person in the least conversant with the imperfect machinery and processes of the iron manufacture as it existed in France some years since, could not have been otherwise than struck with the improved character of those exemplified in the Paris Exhibition. In no country (probably not excepting even this) has so great progress been made in so short a time, in advancing from a state of comparative rudeness to one of considerable perfection, as in France.

The consumption of iron is not so great as in France, though it is increasing rapidly, as may be seen from returns recently given by the British Chargé d'Affaires at Berlin. These returns show that the amount of iron ore raised in Prussia has increased from 1,495,516 tons in 1853, to 2,144,509 tons in 1854; this has taken place in nearly all the producing districts, but chiefly on the Rhine, where the demand has increased from 719,684 to 1,068,656 tons; in Westphalia, from 146,320 to 330,014 tons; in Silesia, from 563,739 to 650,369 tons; in Lower Saxony and Thuringia, from 51,963 to 70,676 tons; in Prussian Brandenburg, from 8084 to 12,731 tons; and in the Upper Zollverein from 6736 to 12,063 tons.

The Iron Ores of Austria, Belgium, &c.—In Austria, all the iron is smelted with charcoal or carbonised peat, and is in consequence of the finest quality; it may be applied to every description of manufacture, from the most ductile wire to the hardest steel. The production is, however, small. The ores are found in Hungary, Styria, Moravia, and Upper Silesia.

In Belgium, both coal and iron are found in equal abundance, and are worked at Charleroi, Liege, and at other places. The ores, which are chiefly hæmatite, are derived from the limestone at the base of the coal measures. A species of bog ore is also extensively used, which is found near the surface, and is said to be washed to free it from impurities.

The Ores of Sweden, &c.—The superiority of the Swedish iron has long been acknowledged, and till recently it has been unrivalled. This arises not only from the purity of the ore—chiefly the magnetic oxide of iron—but in con-

sequence of its being smelted with charcoal only. The quantity is, however, restricted, as the ironmasters are allowed by law only a certain number of trees per annum, in order that the forests may not be totally destroyed. Coal does not exist in either Sweden or Norway.

Turkish Iron Ores.—In 1844 some experimental researches were undertaken by myself at Manchester, at the request of the Sublime Porte, in regard to the properties of iron made from the ores of Samakoff in Turkey. The ores were strongly magnetic, and contained, according to Dumas and others, 62 to 64 per cent. of iron. They consisted of—

One atom iron	28 +	one atom oxygen	8 =	36
Two atoms iron	56 +	three atoms oxygen	24 =	80
Iron .	84	Oxygen .	32	116

Some of these ores have been smelted with charcoal, and some very fine specimens of iron and steel produced. The manufacture is, however, in a languid state in Turkey; and although smelting furnaces, blowing apparatus, forges, rolling-mills, &c., were prepared and sent out from this country, they are to a great extent useless among a people who have deeply rooted prejudices and habitual inactivity to overcome, and everything to learn in all those habits of industry which indicate the rising prosperity of an energetic and an active people.

The Iron Ores of America.—The magnetic, hæmatite, and clay ironstones abound in the United States: the magnetic ores worked in New England, New York, and New Jersey; the hæmatite in Pennsylvania, New York, New Jersey, and other localities; but the greater

part of the manufacture must eventually establish itself in the valley of the Mississippi, west of the Alleghany range, where vast deposits of coal and iron exist, though at present but imperfectly known or developed. The ores in most of these districts are smelted with a mixture of charcoal and anthracite, and the usual limestone flux, and produce a very excellent quality of iron.

The following is an analysis of magnetic ore from the gneiss near New York:—

Protoxide of iron,	25·40
Peroxide of iron,	70·50
Oxide of manganese	1·60
Silica and loss,	2·50
Metallic iron,	68·50

In Nova Scotia some of the richest ores yet discovered occur in exhaustless abundance. The iron manufactured from them is of the very best quality, and is equal to the finest Swedish metal. The specular ore of the Acadian Mines, Nova Scotia, is said by Dr Ure to be a nearly pure peroxide of iron, containing 99 per cent. of the peroxide, and about 70 per cent. of iron. When smelted, 100 parts yield 75 of iron, the increase in weight being due to combined carbon. The red ore Dr Ure states to be analogous to the kidney ore of Cumberland, and to contain—

	(1)	(2)
Peroxide of iron	85·8	84·4
Silica	8·2	8·0
Water	6·0	7·6
	100·0	100·0

The Acadian ores are situated in the neighbourhood of large tracks of forests, capable of supplying almost any

quantity of charcoal for the manufacture of the superior qualities of iron and steel. Several specimens of iron from these mines have been submitted to direct experiment, and the results prove its high powers of resistance to strain, ductility, and adaptation to all those processes by which the finest description of fire and steel are manufactured.

The difficulties which the Government have had to encounter, during the last two years, in obtaining a sufficiently strong metal for artillery, are likely to be removed by the use of the Acadian pig-iron. Large quantities have been purchased by the War Office, and experiments are now in progress, under the direction of Lieutenant-Colonel Wilmot, Inspector of Artillery, and myself, which seem calculated to establish the superiority of this metal for casting every description of heavy ordnance.

There are also some very rich ores at the Nictau mines, as the following analyses by Dr Jackson show. They contain impressions of Silurian tentaculites, spirifers, &c.:—

	Brown Ore, somewhat magnetic.	Red Iron Ore.
Peroxide of iron .	70·20	64·40
Silica . . .	14·40	19·20
Carbonate of lime .	5·60	5·40
Carbonate of magnesia	2·80	3·20
Alumina . .	6·80	1·20
Oxide of manganese	·40	4·40
Water . . .	·00	2·40
	100·20	100·20
* Gain from oxygen.	·20*	·20†
† Over-run, probably carbonic acid from carbonate of lime.	100·00	100·00

As our limits are circumscribed, it will not be necessary

to extend this section further. Suffice it therefore to observe, that in all countries nature has, with a beneficent purpose, interlaid and interstratified the whole surface of the globe with this useful and indispensable material; and it would ill bespeak that high intelligence with which man is endowed if he did not avail himself of, and turn to good account, the immense stores of mineral treasures which are so profusely laid at his feet.

CHAPTER III.

THE FUEL.

THE inquiry into the properties and composition of the ores of iron, and the processes employed for their reduction and subsequent conversion into bars and plates, would be incomplete unless accompanied by descriptive analyses of the fuel by which they are fused. Indeed the results of the operations of smelting, puddling, &c., are so intimately dependent on the quality of the fuel employed, as to render a knowledge of its constituents essential to the manufacture of good iron.

Charcoal was at first universally employed in the manufacture of iron; and on account of its purity compared with other kinds of fuel, and its strong chemical affinities and consequent high combustibility, it is of very superior value, where it can be obtained in large quantities at a moderate cost. This, however, is rarely the case, and hence its use is restricted within very narrow limits in most countries. Charcoal is the result of several processes, in each of which the object is to increase the amount of fuel in a given bulk. The wood being cut into convenient lengths, and piled closely together, in a large heap, the interstices being filled with the smaller branches, and the whole covered with wet charcoal powder, is then set on fire.

Care is taken that only sufficient air is admitted to consume the gaseous products of the wood, so as to maintain the high temperature without needlessly consuming the carbon. After the whole of the gaseous products have been separated, and the carbon and salts only are left, the access of air is prevented, and the heap allowed to cool.

Another and better process is to throw the wood into a large close oven or furnace, heated either by the combustion within it, or by a separate fire conducted in flues around it. By this process, not only is the yield greater and of better quality, from the slower progress of the operation, but the products of the distillation may be preserved and employed for a great variety of purposes. The following results of some experiments by Karsten, show the difference in yield of very rapid and very slow processes:—

Wood.	Charcoal produced by quick carbonization.	Charcoal produced by slow carbonization.
Young Oak . .	16·54	25·60
Old " . .	15·91	25·71
Young Deal . .	14·25	25·25
Old " . .	14·05	25·00
Young Fir . .	16·22	27·72
Old " . .	15·35	24·75
Mean . .	15·38	25·67

These, on the average, give for the quick process 15·3, and for the slow 25·6, being in the ratio of 1 : 1·67, or 0·67 in favour of the quick process.

Peat.—This material seems likely to come into use for smelting iron in countries such as Ireland, where neither coal nor wood are found in abundance. It is purer and

less objectionable than coal, and if properly dried, compressed, and carbonised, would prove a very valuable fuel for the reduction of such ores as we have already described in the section on the iron ores of Ireland. It is carbonised in the same way as the charring of wood. The great objection to peat as a fuel for manufacturing purposes is its lightness and friability. In Ireland, and other places, this has been sought to be overcome by the compression of the peat by powerful hydraulic presses. Thus compressed, the peat loses two-thirds of its volume, and two-fifths of its weight, through the expulsion of part of its water.

Large quantities of peat are carbonised on the Continent in the Vosges, Bavaria, Saxony, and France, and employed in the smelting of iron. The yield of peat charcoal does not exceed 30 per cent. of the raw material when it is charred in open heaps, nor 40 per cent. when the carbonisation is effected in closed kilns. The products of the distillation are sometimes collected, and form valuable articles of commerce.

Coke.—Before the introduction of the hot-blast, this material was used to a very great extent in the manufacture of iron; it is prepared from coal in the same way that charcoal is prepared from wood, the operation being called the coking or desulphurizing process. The heaps do not require so careful a regulation of the admission of air as those of charcoal, on account of the comparatively incombustible character of the coke. Sometimes the heaps are made large, with perforated brick chimneys, to increase the draught through the mounds; at other times they are formed into smaller heaps, and the conversion

takes place without the intervention of flues. The more usual and economical plan is, however, the employment of close ovens, by which process a great saving is effected, the yield being from 30 to 50 per cent. in the one case, and from 50 to 75 in the other, according to the nature and quality of the coal.

Coal.—The hot-blast has enabled the ironmasters to use raw coal in the blast furnaces, the great heat of the ascending current of the products of combustion coking it as it falls in the furnace. The sulphur, however, and other deleterious ingredients, do not appear to be so completely got rid of as when the coal is used in the shape of coke; and it appears probable, that even with the hot-blast, the separate process of coking might be advantageously used, on account of the greater purity of the iron produced.

The facilities of different countries for producing iron depend largely upon the quantity of coal found in their borders. The source of English pre-eminence in this manufacture is due to the large and accessible coal-fields, and their close association with the iron ores. It has been calculated that there are 8139 square miles of bituminous coal, and 3720 of anthracite, in Great Britain, or 1–10th of the whole area of these islands. On the other hand, in France there are only 1719 square miles, or the 1–118th of the area; in Spain, 3408 miles, or the 1–52d; in Belgium, 518 square miles, or the 1–22d. America contains, however, the largest coalfields, British America having 18,000 square miles, or 2–9ths of its whole area; the United States 133,132 square miles of bituminous coal, or 1–17th of the area, and Pennsylvania 15,437 miles of anthracite, or 1–3d of the whole area. (TAYLOR.)

The following tables, selected from various sources, give the composition of the different kinds of fuel, all of which are applicable to the reduction and fusion of the iron ores:—

Fuel.	Locality.	Specific gravity.	Carbon.	Hydrogen.	Oxygen and Nitrogen.	Ashes in 100 parts.	Authority.
Splint Coal.		1·290	75·00	6·25	18·75	...	Thomson.
		1·266	70·90	4·30	24·80	...	Ure.
	Newcastle, Wylam.	1·302	74·823	6·180	5·085	13·912	Richardson.
	Glasgow.	1·307	82·924	6·491	10·457	1·128	
Cannel Coal.		1·272	64·72	21·56	13·72	...	Thomson.
		1·228	72·22	3·93	23·85	...	Ure.
	Lancashire, Wigan.	1·319	83·753	5·660	8·039	2·545	Richardson.
	Edinburgh, *Parrot coal.*	1·318	67·597	5·405	12·432	14·566	
Cherry Coal.		1·263	74·45	12·40	13·15	...	Thomson.
	Newcastle, Jarrow.	1·266	84·846	5·048	8·430	1·676	Richardson.
	Glasgow.	1·286	81·208	5·452	11·923	1·421	
Caking Coal.	Newcastle, Garesfield.	1·280	87·952	5·239	5·416	1·393	
	Durham, South Hetton.	1·274	83·274	5·171	3·036	1·519	
		1·269	75·28	4·18	20·54	4·670	Thomson.
Anthracite.	Swansea.	1·348	92·56	2·330	2·530	1·720	Regnault.
	"	1·270	90·58	2·600	4·100	...	Jacquelin.
	South Wales.		94·05	3·380	2·570	...	Overman.
	Pennsylvania.	1·462	90·45	2·430	2·450	4·670	Regnault.
	"	...	94·89	2·550	2·560		Overman.
	Massachusetts. Worcester.	...	28·35	0·920	2·150	68·65	
	Wales.	1·349	92·79	3·14	2·53	1·45	Schafhaeutl.
Peat.	Vulcaire.	...	57·03	5·630	31·760	...	Regnault.
	Long.	...	58·09	0·930	31·370	...	
	Camp de Feu.	...	57·79	6·110	30·770	...	
	Cappage.	...	51·05	6·85	39·55	2·55	Dr Kane.
	Kilbeggan.	...	61·04	6·67	30·46	1·83	
	Kilbakan.	...	51·13	6·33	34·48	8·06	

The subject of the chemical composition of coal has been most elaborately worked out by Dr Lyon Playfair in a report to the Admiralty, published in the Memoirs of the Geological Survey of Great Britain. The reader must be referred to the original memoir for the details of the elaborate analyses carried out under his direction; all that can be done here is to present a brief summary of his results :—

Average Composition of Coals from different Localities.

Locality.	Specific gravity.	Carbon.	Hydrogen.	Nitrogen.	Sulphur.	Oxygen.	Ash.	Per centage of Coke left by each Coal.
36 samples from Wales	1·315	83·78	4·79	0·98	1·43	4·15	4·91	72·60
18 „ Newcastle	1·256	82·12	5·31	1·35	1·24	5·69	3·77	60·67
28 „ Lancashire	1·273	77·90	5·32	1·30	1·44	9·53	4·88	60·22
8 „ Scotland	1·259	78·53	5·61	1·00	1·11	9·69	4·03	54·22
7 „ Derbyshire	1·292	79·68	4·94	1·41	1·01	10·28	2·65	59·32

According to Knapp, peat contains from 1 to 32 per cent. its weight of ash. In coal we have the following from Mr Mushet's analyses :—

	Specific gravity.	Carbon.	Ashes.	Volatile matter.
Welsh furnace coal .	1·337	88·068	3·432	8·300
„ „ „ . .	1·393	89·709	2·300	8·000
„ slaty „ . .	1·409	82·175	6·725	9·100
Derbyshire furnace coal	1·264	52·882	4·288	42·830
cannel coal	1·278	48·362	4·638	47·000

The following table indicates the composition of the ashes of coal, a subject of the highest importance to the metallurgist, as from this source a part of the impurities are derived. They are quoted from Mr Phillips :—

Locality.	Silica.	Alumina and Oxide of Iron.	Lime.	Magnesia.	Sulphuric Acid.	Phosphoric Acid.	Total percentage.	Per-centage of Ash in Coal.	Per-centage of Coke in Coal.
Pontypool	40·00	44·78	12·00	trace	2·22	0·75	99·75	5·52	64·8
Bedwas .	26·87	56·95	5·10	1·19	7·23	0·74	98·08	6·94	71·7
Porthmawr	34·21	52·00	6·20	0·66	4·12	6·63	97·82	2·91	63·1
Ebbw Vale	53·00	35·01	3·94	2·20	4·89	0·88	99·92	14·72	77·5
Coleshill .	59·27	29·09	6·02	1·35	3·84	0·40	99·97	10·70	—
Fordell Splint Wallsend	37·60	52·00	3·73	1·10	4·14	0·88	99·45	1·50	52·03
Elgin . .	61·66	24·42	2·62	1·73	8·38	1·18	99·99	4·0	58·45

The following table of the heating power of various kinds of fuel, from Knapp's Chemical Technology, is not without interest; in practice, however, only a portion of the absolute heating power is made available:—

	Authority.	Lbs. of water heated from 0° to 100° C. by 1 lb. of fuel.
Charcoal—		
Average	Berthier	68·0
Peat from Allen in Ireland, Upper	Griffith	62·7
Pressed	Griffith	56·6
Lower	Griffith	28·0
Peat charcoal—		
Essone	...	50·7
Framont and Champ de Feu .	Berthier	58·9
Coke—		
St Etienne	Berthier	65·6
Besseges	Berthier	64·3
Rive de Gier	Berthier	58·9
Brown coal—		
Mean of seven varieties . .	Berthier	50·3
Cannel coal, Wigan	Berthier	64·1
Cherry, Derbyshire	Berthier	61·6
Cannel, Glasgow	Berthier	56·4
„ Lancashire	Berthier	53·2
Durham	Berthier	71·6
Gas coke, Paris—	Berthier	50·3
Anthracite	Berthier	
Pennsylvania	Berthier	69·1
Mean of five varieties . . .	Berthier	67·4

In concluding the observations on fuel, we may notice that the various kinds of coal are classed by mineralogists as the bituminous, and stone or anthracite coal. The first class is chiefly employed for the purpose of smelting, though, since the introduction of the hot-blast, anthracite is coming largely into use both in this country and America. Mr Crane of South Wales was the first who attempted the reduction of iron ores by anthracite, and Mr Budd, at his works at Ystalyfera, followed successfully in the same path. To these two gentlemen the public are indebted for having surmounted the obstacles to the employment of this fuel for smelting iron.

On the occasion of a visit to Mr Crane's works, nearly twenty years ago, the writer had an opportunity of inspecting some specimens of anthracite, which had passed through the furnace, and been in contact with the minerals at the temperature of fusion for 48 hours, without having suffered decomposition, and were found to be charred to a depth of only three-fourths of an inch, the interior being of a perfectly shining and black colour, and quite unaffected by the heat of the furnace.

We may mention here Mr Crace Calvert's process for the purification of coke intended for smelting purposes. It is well known how injurious to the quality of iron is the presence of phosphorus and sulphur, both of which are present often in considerable quantities in the ores, and fuel. Sulphur has a tendency to make the iron ~~cold~~-short, and phosphorus to make it ~~red~~ short; and this effect is so deleterious in most cases, that the Yorkshire irons appear to owe their signal superiority to the fact that the bed of coal employed in their reduction and

manufacture is free from these ingredients. Mr Calvert employs chlorine, hydrochloric acid, or chlorides, either by introducing them into the blast-furnace, or in contact with the ores when roasted, or into the coking ovens. Chloride of sodium is preferred in the proportion of 58 parts of the chloride to 16 parts of sulphur, or 32 parts of phosphorus in the ores or coal. The effect is to remove to a great extent the phosphorus and sulphur with which the sodium unites to form a slag.

CHAPTER IV.

THE REDUCTION OF THE ORES.

THE processes for the manufacture of iron, as we have already pointed out, are of two distinct kinds—those of cementation and those of smelting. The product of the former is imperfectly malleable iron; that of the latter, cast-iron, or iron combined with more or less carbon.

Process with the Catalan Hearth.—The first and older process is uncertain in its results, involves considerable expense, and, as there are no efficient means of getting rid of the earthy impurities, necessitates the employment of rich magnetic, specular, or hæmatite ores; on account of these defects, it is now seldom employed. The ores to be reduced by this process were heated with charcoal in open furnaces like the Catalan hearth, the fire being urged by a blast. The oxygen combined with the carbon, and the water and volatile substances were driven off, and the iron—carburized and partially fused—sank to the bottom of the hearth. If the process were stopped at this point, an imperfect cast-iron or steel was the result. But usually the blast was then directed downwards, so as to play over the surface of the iron, and oxidized the greater part of the combined carbon; during this operation the iron became tough and malleable, and fit for the hammer.

The annexed section (fig. 1) shows the disposition of the Catalan hearth during the process of reduction. The fuel and ore B are piled over the hearth A, and ignited; the blast to urge the fire is applied at D, and the gaseous products of combustion pass off by the chimney C.

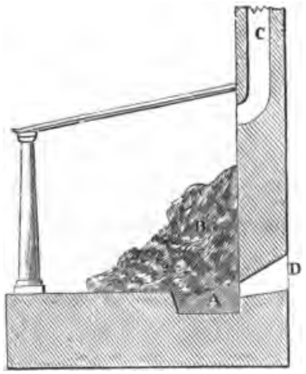


Fig. 1.

The process has been employed in America, where capital was wanting, for the erection of blast furnaces, but it is very wasteful, as is shown by the following statement of the materials employed:—3 tons of rich ore produce 1 ton of iron; 5 hours are necessary to convert a loup of iron weighing only 150 lbs.

Mr Clay's Process.—A similar process has lately been invented by Mr Clay, which appears to reduce the rich ores with great advantage, and to be free from the defects of the older process. Mr Clay mixes the ore with four-tenths of its weight of coal, and grinds it so small that it will pass through a screen of one-eighth of an inch mesh; it is then put into the hopper A (fig. 2), from which it falls upon the preparatory bed B, at the side of the puddling furnace C. While in this position, the ore is heated, and partly decomposed, and the coal coked. The charge is then drawn forward into the reverberatory furnace C, where it is fused by the heat of the gaseous products passing from a fire at D to the chimney F, and is puddled and balled in the ordinary way. The cinder produced con-

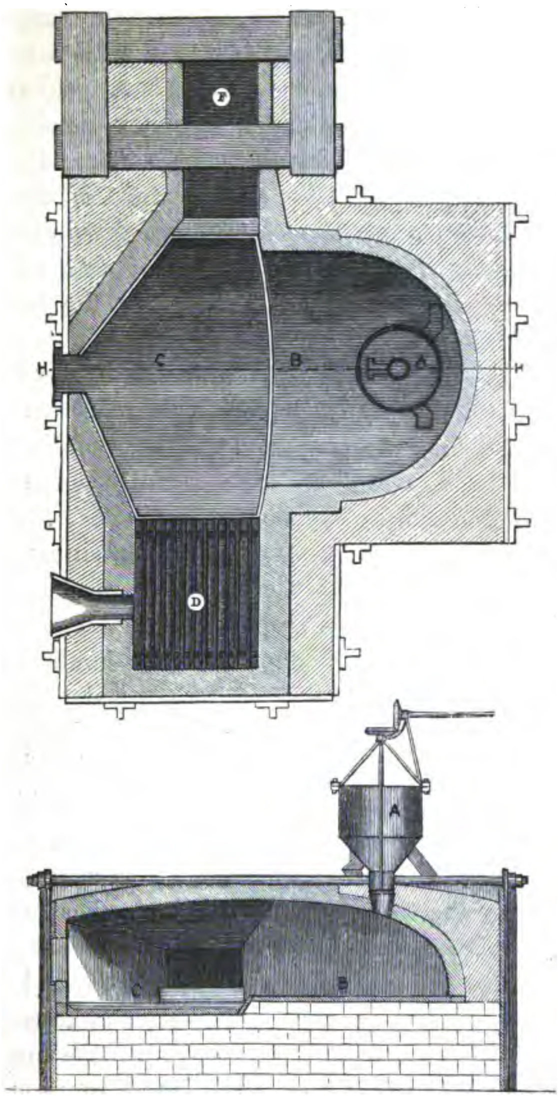


Fig. 2.

tains 50 to 55 per cent. of iron, is free from phosphorus, and is very suitable for smelting in the blast furnace. This process is said to produce puddled bars equal to those made by the four operations of calcining, smelting, refining, and puddling, under the old system, and appears to be peculiarly adapted for the reduction of those rich ores which cannot be smelted advantageously in the blast furnace, because the small quantity of slag which is formed does not protect the metal from the oxidizing effects of the blast.

Smelting.—The process of smelting in the blast furnace is now almost universally adopted for the reduction of iron ores; and for the cheapness and working qualities of the metal produced, as well as for the rapidity of the manufacture, it is decidedly superior to all others.

Calcination of the Ores.—Ores which contain much carbonic acid, water, or volatile matter, were at one time invariably subjected to a preparatory process of calcination; but, since the introduction of the hot-blast, they are now frequently employed in the raw state. The calcination is sometimes effected in the open air, by stacking the ore with coal, setting fire to it, and allowing it to burn out; but this method is liable to serious objection. It is impossible to keep the temperature uniform throughout the heap; and in consequence, while some portions are scarcely affected, others are fused together into large masses, which cannot be smelted without difficulty, even when broken up. Apart from the irregularity and uncertainty of the open air process, it appears to be more expensive than the calcination in kilns, when the admission of air is entirely under command. These ovens or kilns

are usually built of masonry, and are placed, if possible, on a level with the charging platform of the smelting furnace. These kilns are so arranged that the process is continuous, the calcined ore being withdrawn below whilst the process is going on above. The argillaceous ores lose, during this process, 20 to 30 per cent.; the carbonaceous, 30 to 40 per cent. of their weight. In Scotland, the blackband and clay ironstone ores are all calcined, even for the hot-blast, the coally matter in the blackbands being almost sufficient to effect the calcination without other fuel. The carbonaceous ores lose as much as 40 or 50 per cent. of their weight in this process.

The High Cold-blast Furnace.—The blast furnace consists of a large mass of masonry, usually square at the base, from which the sides are carried up in a slightly slanting direction, so as to form, externally, a truncated pyramid. In the sides there are large arched recesses, in which are the openings into the furnace for the admission of the blast, and for running out metal and the cinder; at the top of the furnace is a cylindrical erection of brick-work, called the tunnel-head, for protecting the workmen from the heated gases rising from the furnace, and having one or more doors, through which the charges of ore, fuel, and flux are thrown into the furnace. In front, protected by a roof, is the casting-house, where the metal is run from the furnace into moulds.

Fig. 3 is a vertical section, and fig. 4 a plan of one of the furnaces at the Dowlais Iron Works, which belong to the representatives of the late Sir J. Guest. Mr Truran, in a recently published and elaborate work on iron, has figured and described it. He states that it is one of the

largest class, 38 feet square at the base, diminishing upwards 3 inches for every vertical foot, till it attains a height of 25 feet, where the square form ends with a

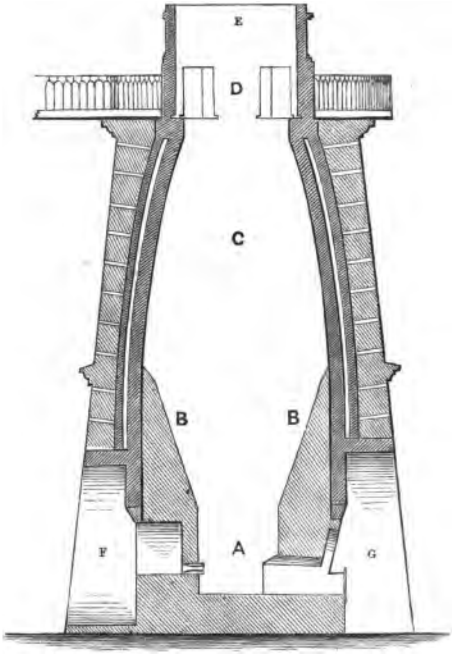


Fig. 3.

moulded cap; above this, the form is circular, diminishing in diameter at a similar rate, and finishing at top with a plain moulded cornice, as a support for the charging platform. In the section and plan A is the hearth, 8 feet high and 8 feet in diameter; BB the boshes, rising to a height of 15 feet, and 18 feet wide at their greatest diameter. From the top of the boshes the body of the furnace contracts, in a barrel-shaped curve, so that

at the charging platform D, at a height of 50 feet, it is only 10 feet in diameter; E is the tunnel-head, with doors of iron, to admit the charges of ore and fuel; FFF

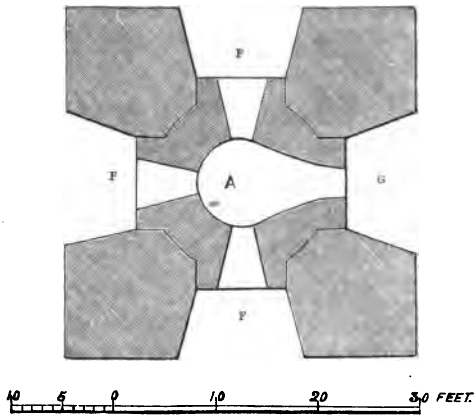


Fig. 4.

the tuyere-houses, arched over and spread outwards, with the openings into the furnace for admitting the blast. G, the opening through which the iron is run from the furnace. The exterior is generally built of stone, and requires to be strongly bound with iron hoops, to prevent fracture from the expansion of the interior by the heat. The interior is lined with fire-brick set in fire-clay, a space of two or three inches being left between the two courses, to allow the expansion of the inner course. The hearth and boshes were usually constructed of refractory sandstone grit, or conglomerate, but fire-bricks are now chiefly used; and, although they do not last so long, they are in the end more economical, and may be replaced whenever the furnace is blown out. The proper inclination of the

boshes is a point of much importance, so that the materials, whilst smelting, may neither press too heavily downwards, nor yet be so retarded as to adhere in a half-liquid state to the brick-work, and cool there, thus forming what are known by the name of *scaffolds*, the removal of which is a source of great inconvenience.

The Cupola Furnace.—Another form of furnace is occasionally used for smelting, called the cupola, and built much more slightly than the blast furnace. Its form is circular, and from the boshes upwards it is constructed of fire-brick, one, or sometimes two courses in thickness. It is strongly bound together with wrought-iron hoops; and pillars of cast-iron, bolted at each end to imbedded rings of the same metal, rise through the foundation to the summit of the tuyere arches, giving considerable firmness and stability to the structure. Cheapness and facility of construction are much in its favour; and although objections have been made to the thinness of its sides, as permitting great loss of heat by radiation, it has met with very general adoption.

In addition to the cupola furnace, another of the same character has of late years been introduced. It consists of a truncated cone, composed entirely of boiler-plates rivetted together, as per annexed fig. 5. On the four opposite sides, recesses are cut to admit the tuyeres and the opening from the hearth into the casting-house. The interior of the furnace is lined with fire-brick and fire-clay in the usual way, and this plate furnace is not only perfectly secure, as regards the expansion and contraction, but it is found to be economical and to answer every purpose in common with the large stone and iron-bound furnaces.

Fig. 5 exhibits a plan and elevation of this description of furnace, the parts AAA being the tuyere-houses, and B the opening for the discharge of the metal from the furnace.

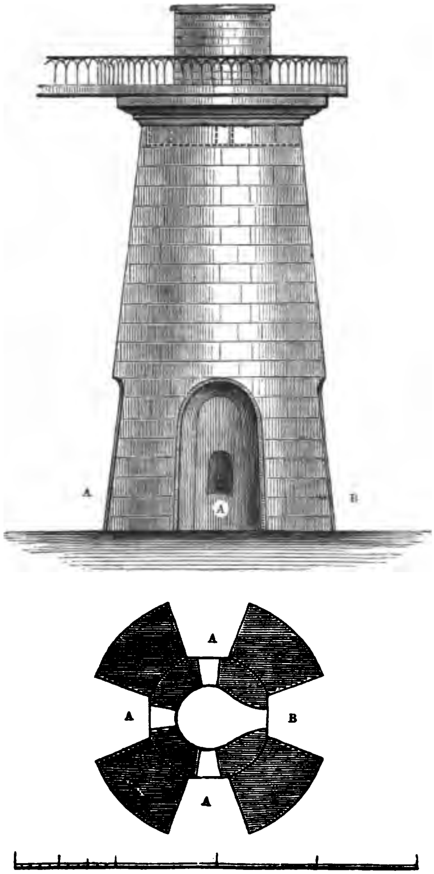


Fig. 5.

The Blast.—The blast is usually created by a steam engine; a piston being attached to the extremity of the beam,

working in a cylinder of large diameter, and forcing the air through proper valves into a large spherical or cylindrical reservoir, constructed of boiler-plate, whence its own elasticity causes it to flow in a regular, unintermitting stream into the furnace. A cylindrical vessel, open at bottom, and immersed in a pit of water, has sometimes been used to regulate the pressure of the blast; but the water evaporated is detrimental to the working of the furnace. The nozzles by which the blast is directed into the furnace are made of cast or wrought iron, and sometimes a current of water is conveyed round their extremities to keep them cool. The number of blowpipe nozzles to each furnace varies at different works; the usual number is three, one for each of the tuyere-houses, but sometimes six, eight, or twelve are employed, as shown in fig. 19; it however appears questionable whether this is not objectionable, as the density and penetrating power of the blast is considerably diminished by this system of diffusion. This, however, is a point which can only be decided by practice, and must be left to the judgment of the smelter. The usual pressure of the blast as it enters the furnace is about 3 lbs. per square inch, but in some cases it is as much as 5 lbs. per square inch.

The Scotch iron-smelters allege that the diffusive power of the blast is increased rather than diminished by increasing the number of blowpipe nozzles, and give as a reason for the use of six or more, that they can be so much more easily repaired, the stoppage of one not materially affecting the working of the furnace.

The dimensions and form of the blast furnace vary greatly, according to the fashion of the district, and the

notions of the builder. Yet so much does the quantity and quality of the iron depend upon the size of the furnace and strength of the blast, that we may venture to assert that the production varies in the ratio of the cubical contents of the furnace, and the volume of air admitted. Mr Truran gives the following particulars of the Dowlais Foundry iron furnace:—"The capacity is 275 cubic yards. It is blown with a blast of 5390 cubic feet of [cold] air per minute. The materials charged at the top consist of calcined argillaceous ore, coal, and limestone. The yield or consumption averages 48 cwts. of calcined ore, 50 cwts. of coal, and 17 cwts. of broken limestone, to 20 cwts. of crude iron obtained. The weekly make of iron is occasionally over 130 tons. The weekly product of cinder amounts to 250 tons. For the production of white iron for the forge, in furnaces of the same capacity as the foregoing, a larger volume of blast is employed, along with a different burden of materials. The blast averages 7370 feet per minute. The consumption of materials to one ton of iron averages 28 cwts. of calcined argillaceous ore, 10 cwts. of hæmatite, 10 cwts. of forge and finery cinders, 42 cwts. of coal, and 14 cwts. of limestone. With these materials the weekly produce amounts to 170 tons of crude iron, and 310 tons of cinder."

Action within the Blast Furnace.—The action which takes place in the blast furnace is as follows:—The contents being raised to an intense heat by the combustion of the fuel, are brought into a softened state; the limestone parts with its carbonic acid, and combining with the earthy ingredients of the ironstone, forms, with them, a liquid slag, whilst the separated metallic particles,

descending slowly through the furnace, are deoxidised and fused. In their passage they combine with a portion of carbon, and at last settle down in the hearth, from whence they are run off into pigs about every twelve hours; the slag, being lighter, floats upon the surface of the liquid metal, and is constantly flowing out over a notch in the dam-plate, level with the top of the hearth. This slag indicates, by its appearance, the manner in which the furnace is working. Thus, if the cinder is liquid, nearly transparent, or of a light greyish colour, and has a fracture like limestone, a favourable state of the furnace is indicated. Tints of blue, yellow, or green are caused by a portion of oxide of iron passing into the slag, and show that the furnace is working cold. The worst appearance of the cinder is, however, a deep brown or black colour, the slag flowing in a broad hot rugged stream, and indicating that the supply of coke is not sufficient to deoxidise the whole of the iron.

During the process of smelting, the interior of the furnace requires to be very carefully watched. The stream of air constantly rushing in at the tuyeres, exerts a chilling agency on the melted matter directly opposed to it at its entrance. The consequence of this is the formation of rude perforated cones of indurated scoriæ, stretching from either side horizontally into the furnace, each one having its base directly over the embouchure of a blast-pipe. When these project only to a certain extent, they are favourable to the working of the furnace, as the blast is thrown right into the centre, and prevented from passing up the sides and burning the brickwork. Sometimes, however, when the furnace is driving cold

and slow, these conduits of slag become so strong, and jut out so far as to meet in the middle, and thus cause a great obstruction to the entrance and ascent of the blast. When this happens, there is usually no remedy but to increase the burden—that is, to increase the quantity of *mine* or ore to the charge. This causes an intense heat; the furnace is said to work hot, and the conduits of slag drop off from the sides. This, however, is followed by bad as well as good consequences: the brickwork is frequently melted, and, for a time, the iron produced is small in quantity, and of the worst quality. To bring the furnace again to its proper state, the burden must be reduced; the sides then become cool, new tubes of slag are formed, and the iron produced is good. These slags are imperfectly vitrified silicates, the composition of which was found by Berthier to be, in the case of a specimen from Merthyr Tydvil—

Silica,	40·4
Lime,	38·4
Magnesia,	5·2
Alumina,	11·2
Oxide of iron,	3·8
Sulphur,	traces
	99·0

At the end of every twelve hours, more or less, the furnace is tapped; that is to say, the aperture in the damstone, which, at the commencement, had been stopped up with a mixture of loam and sand, is re-opened, and the metal contained in the hearth allowed to flow out into moulds, made in the sand of the cast-house floor, thus forming a cast or sough of pigs. When this opera-

tion ceases, the dam-stone is again secured, and the work proceeds as before. In this manner a furnace is kept continually going, night and day, and never ceases to work until repairs are necessary. Incessant action has even been thought necessary to the successful carrying on of iron-works ; but the example of perhaps the largest ironmaster in South Wales has shown, contrary to general practice in that district, that smelting may be discontinued for at least one day in the week without any very serious derangement of operations.

Elevation of Materials to the Tunnel-head.—The communication between the ground and the tunnel-head is effected in various ways. In South Wales the furnaces are usually built on a declivity, which affords ready means of access from behind, the furnace being charged by wheeling the materials on a level platform extending from the higher ground to the tunnel-head of the furnace. Where this is not possible, an inclined plane has been used, with two lines of railway worked by a steam-engine, the trucks being connected so as to balance one another. The pneumatic lift has also been employed, consisting of a cast-iron cylinder inverted in a well of water, and balanced like a gasometer, so that it could move upwards or downwards in a vertical direction. A pipe from the blowing-engine is introduced under the cylinder ; so that the materials being wheeled upon the top, and the blast turned into it, the pressure of the air at once raises it, with its load, to the level of the charging platform.

Thus far we have confined our observations to the production of iron by the cold-blast process; we have

now to consider the changes introduced by the employment of a heated blast.

The Hot-blast Process.—In the year 1828, Mr J. Beaumont Neilson, a practical engineer at Glasgow, took out a patent for an "improved application of air to produce heat in fires, forges, and furnaces, where bellows or other blowing apparatus are required." Mr Neilson proposed to pass the current of air through suitably shaped vessels, where it was to be heated *before it entered the furnace.* In this simple substitution of a hot-blast heated in a separate apparatus, for a cold-blast heated in the furnace itself, consists the whole invention.

Like most other improvements, the progress of this was at first slow. Retarded by practical difficulties, which beset all new processes in their first use—stopped every now and then by the prejudices of custom and ignorance, which cling with inveterate tenacity to maxims of established practice, and repel indiscriminately innovations which improve and those which modify without improving—the invention was more than once on the point of being abandoned. A great part of the interest in its possible remuneration was transferred by the inventor to strangers, whose combined efforts and influence were necessary to insure its success. But though thus tardy in its first steps and feeble in its early efforts, the hot-blast process is now adopted at the greater number of the iron-works of Great Britain, and other parts of Europe and America.

It is perhaps not generally known that practical men, previous to Mr Neilson's invention, universally believed that the colder the blast the better was the quality and

quantity of the iron produced; and this opinion appeared to be confirmed by the fact that the furnaces worked better in winter than in summer. Acting on such views, the iron-master actually in some cases resorted to artificial means of refrigeration, to reduce the temperature of the blast before it entered the furnace. The fact of the improved action of the furnace in winter may perhaps be explained as a

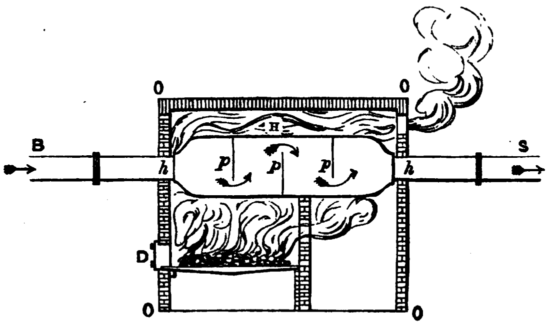


Fig. 6.

consequence of the diminished amount of aqueous vapour contained in the atmosphere in cold weather; and the opinion that the low temperature is the cause of the alleged increase of production has been shown to be wrong by the success of Mr Neilson's invention.

This simple invention affects only the transit of the air from the blowing cylinder to the furnace, an oven or stove being interposed, through which, in appropriately shaped vessels, the air is conducted, and in which it is heated to 600° or 800° Fahr., or to any other temperature adapted for the purpose of smelting.

Mr Neilson's earliest hot-blast oven for smelting purposes consisted of a wrought-iron chamber about 4½ feet

long by 3 feet high and 2 feet wide, set in brickwork like a steam-boiler. This was then replaced by a cast-iron retort, similar to that shown in fig. 6.

In an oven of brickwork 0000, with a fire fed by the door D, a large cylindrical tube or receiver *h h*, about 3 feet in diameter, and 8 or 10 feet long, was placed. The pipes B and S, attached to the receiver *h h* at the opposite ends, communicated with the blowing-cylinder and smelting-furnace respectively. Lunular-shaped partitions *p p p*, projecting from opposite sides on the interior of the receiver, caused the air passing through it to impinge alternately first on one side and then on the other, in order that the temperature might be uniformly and effectively communicated from the metal to the blast. By this means a moderate current of air has been heated up to 300° or 400° Fahr.

Long ranges of tubes, variously designed, were then introduced to increase the heating surface as much as possible, and it was with this arrangement that a temperature of 600° Fahr. was first attained.

Calder Heating Apparatus.—Figs. 7, 8, 9, and 10, show the apparatus first employed, we believe, by Mr Dixon at Calder, and hence generally called the Calder pipes. As erected at the Butterley Iron-Works, Derbyshire, the apparatus consists of two parallel horizontal pipes, LL, fig. 7, called technically the "lying pipes," one communicating with the cold-blast inlet pipe B, the other with the hot-blast outlet pipe S, fig. 9. Into sockets formed in these, the ends of the arched heating pipes *h h h* fit tightly, as shown in fig. 7 and in fig. 8 upon a larger scale. The air, therefore, entering the inlet pipe B, figs. 9 and 10,

passes over the transverse arched pipes *h h*, where it is exposed to the action of a large surface of heated metal, and is delivered into the hot-blast pipe S, which conveys it at the required temperature into the blast furnace. The whole apparatus is enclosed in the oven or furnace 0000, as shown in the figs. 7, 9, and 10.

The figures of the transverse pipes vary considerably

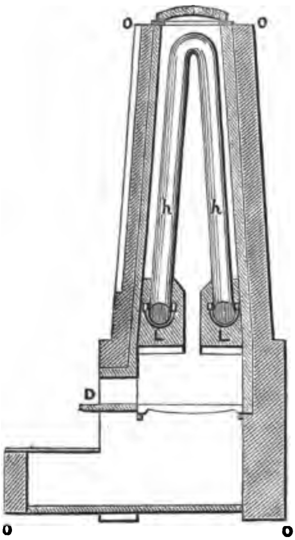


Fig. 7. End Elevation.

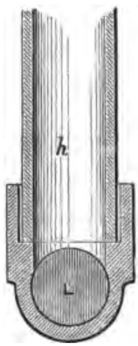


Fig. 8. Joint of Heating Pipe in Lying Pipe.

at different iron-works. Sometimes they rise up and form a large semicircular arch over the fire, 8 or 10 feet perpendicularly, and are then connected by an arch at the top; sometimes they cross the fire in the form of a pointed arch, variously acuminate, or a single large tube is used, traversing the furnace in a long spiral direction. Their cross-section is as various as the form in which they are

bent; pipes of circular, flattened elliptical, rectangular, heart-shaped, and other sectional forms have been em-

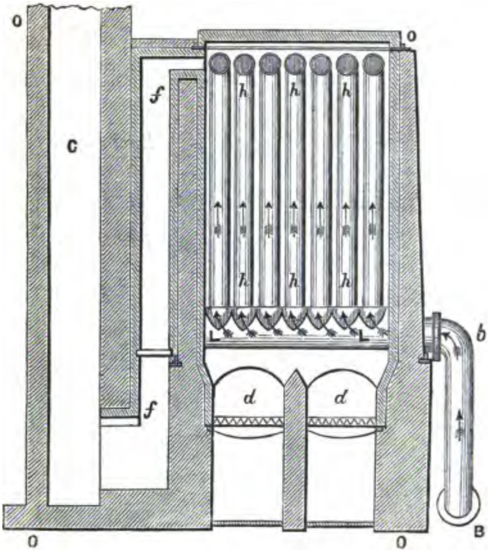


Fig. 9. Elevation.

ployed, in order to increase the heating surface in propor-

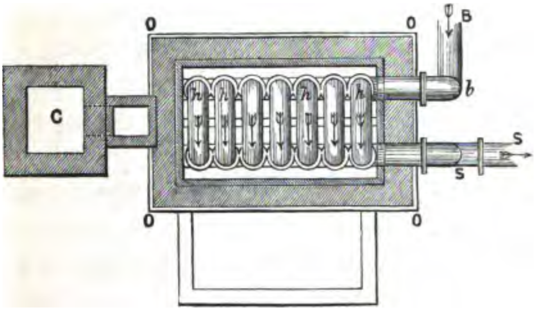


Fig. 10. Plan.

tion to the volume of the blast. All these forms of ap-

paratus, although admirably adapted for heating the air,

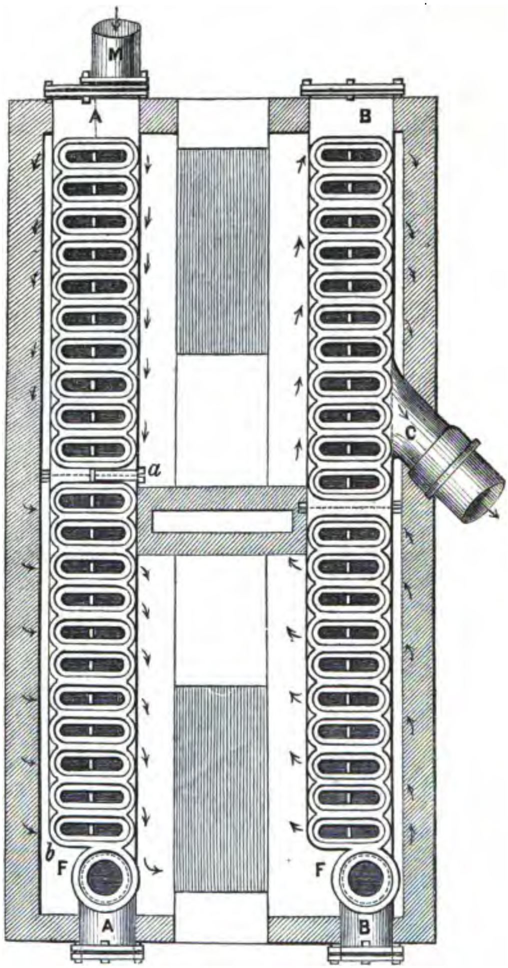


Fig. 11.

are liable to fracture and leakage, from the unequal expansion of the metal.

One other form of apparatus, represented in the preceding figures, Nos. 11, 12, and 13, demands notice, on account of its great heating power. The cold air enters by the pipe M into one side of the lying pipe A A, which is divided down the centre by a partition or diaphragm, and then passes up one side of the heating pipes, which are

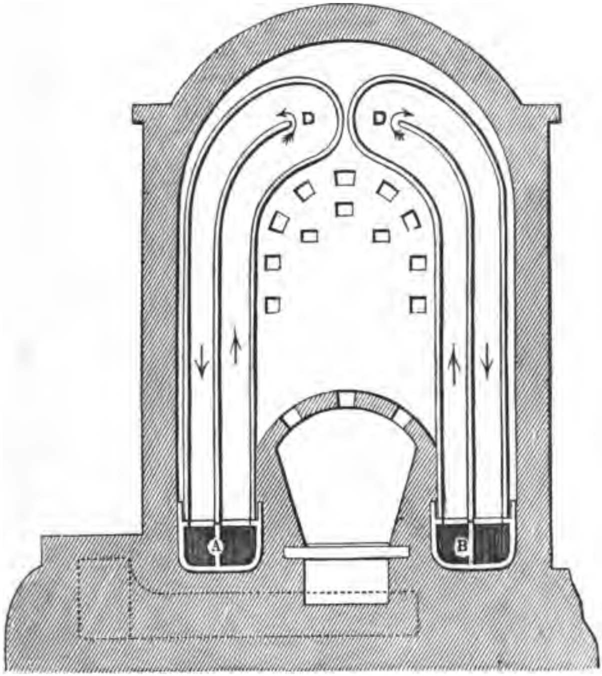


Fig. 12.

also divided by partitions; it then turns round at the top, as shown at D (fig. 12), and descends in the direction of the arrows into the lying pipe A A on the other side to that which it entered. It is thence conveyed by the

arched pipe E (fig. 13) into the second divided pipe B B, through another series of heating pipes, and ultimately escapes by the outlet pipe C, at a high temperature, to the smelting furnace. The diaphragm pipes are, however, not generally used.

The best arrangement is exhibited in the drawing of one of the furnaces and heating apparatus of the Coltness

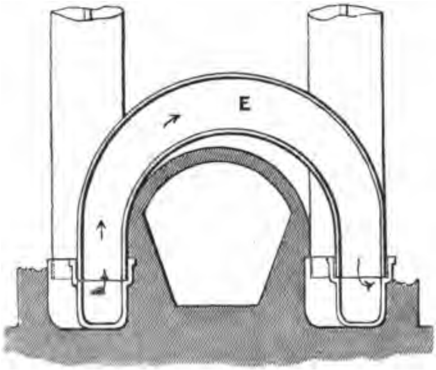


Fig. 13.

Works, kindly furnished by Mr Hunter, the intelligent managing partner of that establishment. The drawings (figs. 14 and 15) represent a sectional elevation and plan of a very successful and regular working hot-blast furnace; but the size and form, as already observed, require to be governed by the quality and nature of the materials that are to be used.

To obviate the tendency to fracture of the iron tubes at the crown of the arch, from the expansion of the metal, due to the very high temperatures to which it is subjected, only one lying tube is made fast in some cases, and the other placed upon rollers to give as much freedom as

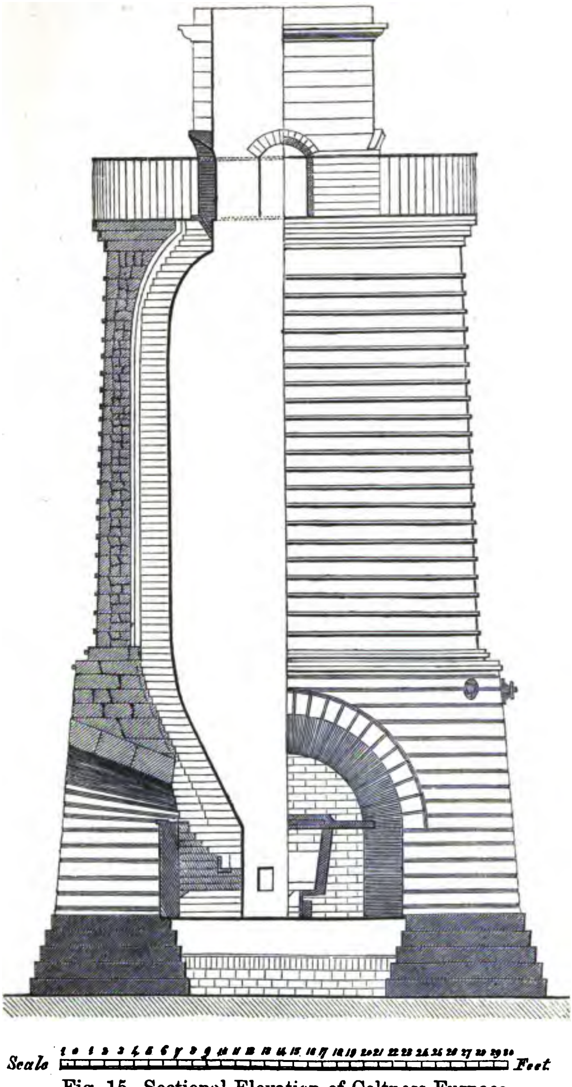


Fig. 15. Sectional Elevation of Coltness Furnace.

possible for the motion of the pipes and the reduction of the strain.

The following dimensions of the West Staffordshire ovens have been given by Mr Martin of Wolverhampton :—

Length inside casing . . .	16 feet.
Breadth	7½ „
Number of siphon pipes . . .	16 „
Effective area of heating surface . .	700 sq. ft.
Total area of fire grate . . .	35 „

--an oven of these dimensions being capable of heating the blast for four tuyeres to a temperature of 600° or 700° Fahr.

The latest improvement of the hot-blast oven has been the introduction of round ovens. The following example (fig. 16) is taken from a series described by Mr Marten,

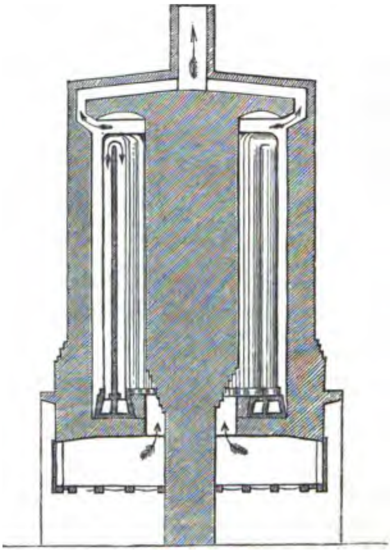


Fig. 16.

as constructed under his directions in 1857. In this, two *circular* main lying pipes are used, and the siphon pipes

are arranged upon them in a circle, as shown in figure 16. A large brick core is introduced, which increases the reverberatory action on the pipes, and maintains the temperature more uniform. The area of the fire-grate in this oven is 38 square feet, and the area of direct heating surface in the pipes 850 square feet. It is capable of heating the blast for three tuyeres to 800° Fahr. In this furnace the horizontal expansion takes place almost entirely in the lying pipes, and has no effect in fracturing the siphons, so that the leakage and danger of fracture is reduced to a minimum.

In regard to the consumption of fuel in these ovens, it is sometimes as much as 9 cwts., and at others as low as 5 cwts. per ton of iron produced in the blast furnace.

Another hot-blast stove, which has recently been employed at Messrs Cochrane's works at Ormesby, near Middlesborough, has been described by Mr Cowper to the Institute of Mechanical Engineers. In this case a pair of stoves is used, the blast being turned alternately at intervals of an hour or two hours through each. They consist of brickwork chambers filled loosely with fire-brick or other refractory substance, and heated from the bottom by coal fires. The products of combustion pass upwards through the brickwork, heating it in passing till they emerge at the top and pass away to the chimney at a comparatively low temperature. After the chamber is thoroughly heated, the fire is shut off and the cold blast passed in, so that, passing downwards from the colder to the hotter part, it reabsorbs the heat imparted to the fire-bricks. Meanwhile the other stove is being heated in a similar way; and after two hours' work, more or less accord-

ing to the size of the stoves, the blast is turned into the second stove, and the products of combustion allowed to reheat the first.

The only means we possess at present of the working of these stoves will be found in Mr Cowper's paper. The following abstract gives the most interesting facts elicited during two months' working of a pair of these stoves, supplying a single tuyere with 1000 cubic feet of air per minute :—

Cubic contents of fire-brick in stove, . .	250 feet.
Heat of escaping gaseous products in chimney,	150° to 250°
Temperature of blast after passing through the regenerative stove, ...	1300°
Variation in the temperature of the blast during two hours' work, ...	100° to 150°
Outside diameter of stoves, ...	7 feet 6 inches.

The prospective advantages of these regenerative stoves are greater economy from the use of cheap fire-brick surfaces instead of the costly iron pipes, which are so apt to cause leakage at the joints and to deteriorate in use ; and the higher temperature attainable by the blast, owing to the fact that the heat is received direct from the surfaces heated, instead of being conducted through a thick metal casing.

The more difficult the reduction of the ironstone the smaller must be the diameter of the hearth, so as to enable the blast to penetrate and circulate throughout the whole of its contents. In other conditions, where the ores are easily reduced, hearths of 9 feet diameter have been introduced with great advantage, and that without detriment to the quality of the iron produced. The diameter of the body of the furnace is likewise regulated by the quality of the materials used, and in cases where the coal

is culm or anthracite and the ore hard, a large diameter is found to work very irregularly; and the results have been, where furnaces have been erected 18 feet diameter, to have them reduced to only 9 feet.

The height of the furnace is also regulated by the nature of the materials and the strength of the blast by which they are reduced. Sometimes, when the coal is soft, and crushes by the superincumbent pressure, it is bound or compressed to such an extent as to prevent the blast penetrating the mass, and causes an irregular working of the furnace; and, moreover, under these conditions, it makes what is called white or silvery iron.

The pressure of the blast requires also to be regulated to suit the materials, and, according to the workings at Coltness (shown in figs. 14 and 15), the pressure is about 4 lbs. on the square inch, and as much as 10,000 cubic feet of air is discharged into the furnace per minute. The temperature of the blast is 600° Fahr., and the area of the heating surface of the apparatus for raising that temperature is 3500 square feet.

The quantity of materials to make a ton of iron at these works varies in some relative proportion to their densities; but the following may be taken as a fair average of the consumption of fuel, ore, limestone, &c.:—

	Ton	cwt.
Of raw coal,	1	10
Of calcined ironstone,	1	17
Of broken limestone,	0	12
Of coal for heaters,	0	4
Of coal for blowing engine,	0	4

With the above charges the furnaces will produce from 168 to 170 tons per week, or 8700 tons of good iron per annum.

The usual proportion of materials for the smelting

furnace is, in Staffordshire, with the argillaceous ores, 3 tons of coal and 15 or 18 cwt. of limestone to 1 ton of iron produced, the blast being heated to about 600°, and introduced under a pressure of 2½ to 3½ lbs. per square inch; 2 to 3 tons of ores are needed to make 1 ton of iron, according to the richness of the ironstone. If we compare this with the Yorkshire cold-blast works, using coal and smelting similar ores, we find that, on the average, 4 tons of coal and 20 cwt. of limestone are required to produce 1 ton of iron, the amount of ironstone needed being 3½ tons. If, in this latter case, coke is used, the amount of fuel needed, however, is only 2½ to 3 tons, and 11 to 17 cwt. of limestone.

In South Wales, at the anthracite furnaces, where, of course, hot-blast is employed, the burden is about 3 tons 7 cwt. of argillaceous carbonate, 1 ton 15 or 1 ton 17 cwt. of anthracite, and 17 cwt. of limestone, to 1 ton of iron produced.

In Scotland, with blackband ores, about 1 ton 16 cwt. of calcined ironstone is used to 2½ tons of coal and 10 cwt. of limestone to produce one ton of iron, inclusive of the fuel needed for the hot-blast ovens, and blowing engine.

Hot-blast Furnace.—Figs. 17, 18, and 19 show the general arrangement and the disposition of a hot-blast furnace, and the apparatus connected with it. J is the blowing cylinder, from which the air is forced into the receiver K, made of wrought-iron boiler plate; from this it passes by the pipe L into the heating ovens, one of which is shown in section at M, and the pipe N conducts it, when heated, to the furnace. PPP are the tuyeres, FF the charging doors, E the tunnel-head.

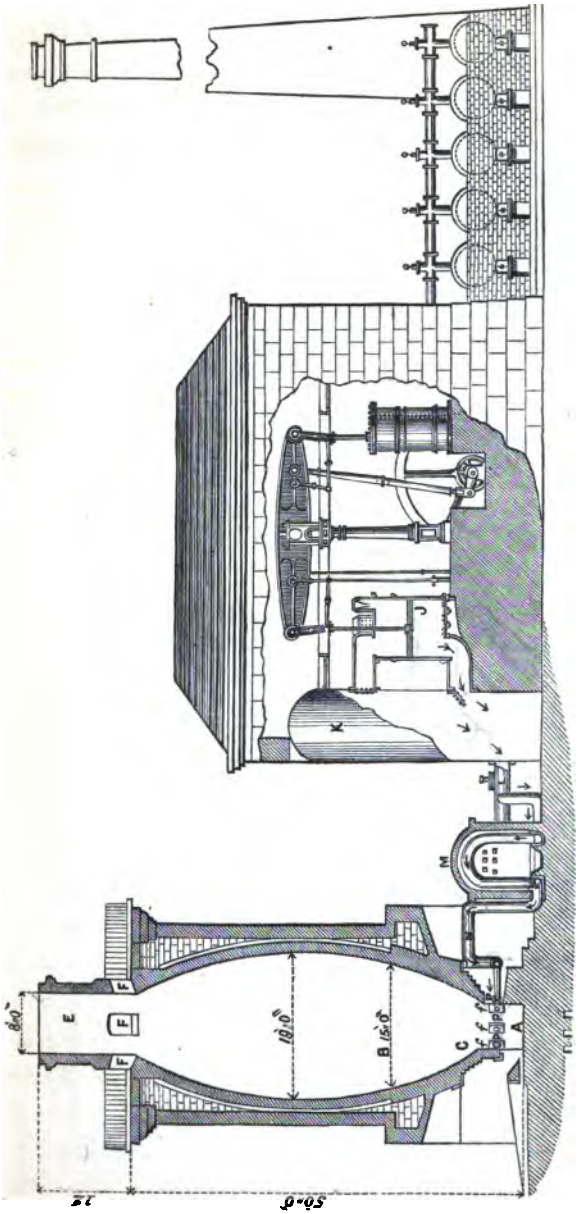


Fig. 17. General Arrangement.

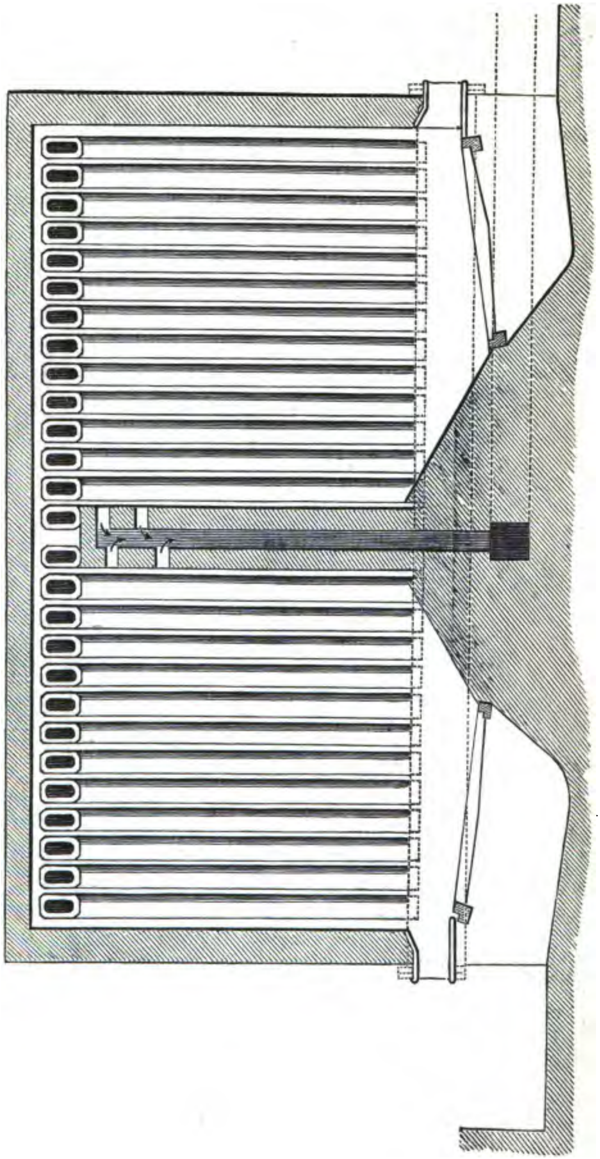


Fig. 18. Hot-blast Stove.

With regard to the advantages and defects of the hot-blast process, much has been said on both sides, and the question does not appear by any means exactly settled. It is asserted, on the one hand, that iron reduced by the hot-blast loses much of its strength, whilst, on the other, it is contended that the quality of the iron is richer, more

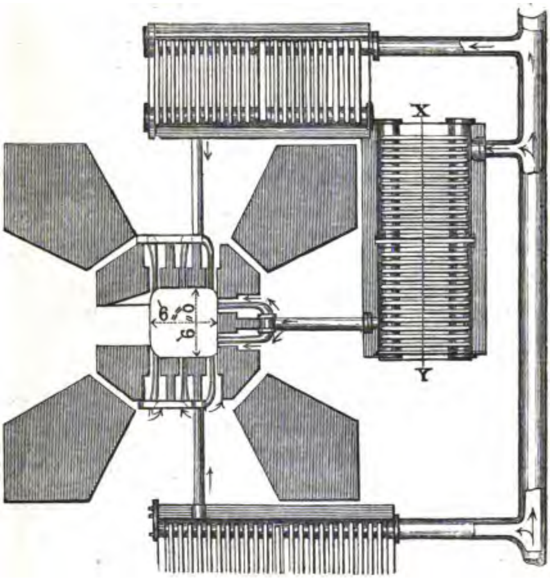


Fig. 19. Plan.

fluid, and better adapted for general purposes than that produced by the cold-blast. The advocates of the hot-blast say that the process has increased the production and diminished the consumption of coal three or four fold; and the upholders of the cold-blast maintain that the same effects may be produced, to almost the same extent, by a judicious proportion of the shape and size of the interior

of the furnace, a denser blast, and greater attention on the part of the superintendent to the process.

On these points it appears to us, that although the hot-blast has enabled the manufacturer to smelt inferior ores, cinder heaps, and other improper materials, and to send into the market an inferior description of iron, this is no reason for its rejection, but rather an argument in its favour. It is true that when a strong rigid iron is required for such works as bridges or artillery, the somewhat uncertain character of hot-blast metal renders it objectionable, but this appears to be due rather to carelessness or want of attention in the manufacture than to the use of heated air or defects in the process. On the other hand, the hot-blast, by maintaining a higher temperature in the furnace, ensures more effectually the combination of the carbon with the iron, and produces a fluid metal of good working qualities, generally superior to cold-blast iron, in cases where great strength is not required ; and, moreover, we have yet to learn why even the strongest and most rigid iron cannot be made by this process. The comparative strength of hot and cold blast iron will, however, be given in another part of this treatise ; for the present it is sufficient to observe, that the results of the experiments are not unfavourable to the hot-blast iron, either as regards its resistance to a transverse strain, or its power to resist impact.

Dr Clark, Professor of Chemistry in the University of Aberdeen, investigated the merits of the hot and cold blast process, in regard to the consumption of fuel, as early as 1834–5. He states, that after the hot-blast had been brought fully into operation at the Clyde Iron-Works,

"during the first six months of the year 1833, one ton of cast-iron was made by means of 2 tons 5¼ cwt. of coal, which had not previously to be converted into coke; adding to this 8 cwt. of coal for heating, we have 2 tons 13¼ cwt. of coal required to make one ton of iron. In 1829, when the cold-blast was in operation, 8 tons 1¼ cwt. of coal had to be used. This being almost exactly three times as much, we have from the change of the cold-blast to the hot, combined with the use of coal instead of coke, three times as much now made from the same quantity of coal." Dr Clark adds the following statistics of the Clyde Iron-Works:—

In 1829, the weekly produce of three furnaces, cold air and coke being used, was 110 tons 14 cwt.; and the average of coal to one ton of iron was 8 tons 1 cwt. 1 qr.

In 1830, the weekly produce of three furnaces, coke, and air at 300° Fahr. being used, was 162 tons 2 cwt.; and the average of coal to one ton of iron was reduced to 5 tons 3 cwt. 1 qr.

In 1833, the weekly produce of four furnaces, *raw coal*, and air heated to 600° being used, was 245 tons; and the average of coal to one ton of iron was reduced to 2 tons 5 cwt. 1 qr.

"On the whole, then, the application of the hot-blast has caused the same fuel to reduce three times as much iron as before, and the same blast twice as much."

This decrease in the amount of fuel and blast required for the reduction of iron, Dr Clark accounts for by showing, that in an ordinary furnace, "2 cwt. of air a minute, or 6 tons an hour, are ejected into the furnace." This he considers "a tremendous refrigeratory passing through the hottest part of the furnace," and to a great extent repressing the temperature which is necessary for the complete and rapid reduction of the iron.

Mr Truran considers that "writers on the hot-blast

have greatly exaggerated the effects of this invention on the iron manufacture of this country. If we are to believe the majority of them, the great reductions which have been effected within the last twenty-five years, in the quantities of fuel and flux to smelt a given weight of iron, and the large increase of make from the furnaces, is entirely owing to the use of this invention. That the hot-blast, under certain circumstances, has effected a saving in the consumption of fuel, and also augmented the weekly make, we freely admit. But the saving of fuel, and increase of make due to its employment, is not generally one-fourth of the quantity which writers have asserted." Here Mr Truran is at issue with Dr Clark, and denies the cooling effect of a cold-blast. He attributes the effects of a heated-blast, "first, to the caloric thrown into the furnace along with the blast, enabling a corresponding quantity of coal to be withdrawn from the burden of materials, with a proportionate reduction in the volume of blast, the effects of which are seen in an augmentation of the make, but do not result in any saving of fuel; secondly, to the reduced volume of blast and large proportion of caloric which it carries into the furnace, causing a diminished consumption of fuel in the upper parts of the furnace." Although we do not agree with all Mr Truran's strictures on the hot-blast, the consumption of fuel in the throat is, nevertheless, a question well worthy of investigation. The combustion is of course largely increased by the narrow form of throat given to furnaces, which greatly increases the effect of the blast there, and accounts for the difficulty of using those kinds of coal, in the raw state, which

splinter if rapidly heated. If Mr Truran's conjectures be correct, and it be found that, by increasing the area of the throat, raw coal and anthracite can be advantageously used with a cold-blast, the superiority of the hot-blast will not be so decidedly marked. This must, however, be determined by practice; as at present certainly it is well known that the anthracite and splint coal can be used most effectively and economically with the hot-blast.

We quote from one more authority on this subject. M. Dufrénoy, in his report to the Director-General of Mines in France, states, that upon heating the air proceeding from the blowing cylinder up to 612° Fahr., a considerable saving in fuel was effected by the use of raw coal instead of coke, and that this caused no derangement of the working of the furnace or deterioration of the iron produced. On the contrary, "the quality of the metal was improved, and a furnace which, when charged with coke, produced only about half No. 1 and half No. 2 pig-iron, gave a much larger proportion of No. 1 after the substitution of raw coal. Besides this, the quantity of limestone was considerably diminished." This last circumstance, according to M. Dufrénoy, is due to the increased temperature of the furnace, which fuses more readily the earthy matter and other impurities in combination with the ores.

To show the saving effected, M. Dufrénoy gives the quantities used in each of the experiments at the Clyde Iron-Works:—

In 1829, the combustion being produced by cold air, the consumption for one ton of iron was—

	Tons.	cwts.	Tons.	cwts.
Coal—for fusion, 3 tons of coke corresponding with . . .	6	13		
„ for blowing engine . . .	1	0		
Total coal used			7	13
Limestone			0	10½

In 1831, the furnace being blown with air heated to 450° Fahr.—

	Tons.	cwts.	Tons.	cwts.
Coal—for fusion, 1 ton 18 cwt. coke, corresponding with . .	4	6		
„ for the hot-air apparatus . .	0	5		
„ for blowing engine . . .	0	7		
Total coal used			4	18
Limestone			0	9

In July 1833, the temperature of the blast being raised to 612 Fahr. and the fusion effected by *raw coal*, the consumption per ton of iron was—

	Tons.	cwts.	Tons.	cwts.
Coal—for fusion	2	0		
„ for the hot-air apparatus . .	0	8		
„ for blowing engine . . .	0	11		
Total coal used			2	19
Limestone			0	7

Since that time, the employment of a blast heated to 800° or 900° has still further increased the weekly production and saving of fuel.

It has been considered, and no doubt with truth, that the introduction of the hot-blast has led to the reduction of inferior ores, and that the deterioration commonly ascribed to hot-blast iron has arisen from that cause. To some extent this may be the case; but we must look to another cause for many of the anomalous conditions of iron from the same furnaces. If it could be traced to the ores alone, there is at once a solution of the difficulty; but the use of raw coal and uncalcined ore, with an elevation of temperature arising from the heated blast, and causing the reduction of a larger quantity of impurities,

has doubtless something to do with the variable products which proceed from the process. Time, and the purification of the ores and fuel previous to smelting, appear to be essential to the production of good iron; and hence it follows that the high temperature, together with the impurities of the material, is more likely to produce iron of inferior quality than the old process with duly prepared ores and fuel. With this proviso, it does not appear that the hot-blast necessarily deteriorates the iron produced.

The Gases formed in the Blast Furnace.—The subject of the gaseous products formed in smelting furnaces at various depths, has been studied with great care by Messrs Bunsen and Playfair; and the results of their investigations are to be found in a report addressed to the British Association in 1845. The apparatus they employed consisted of a system of malleable iron tubes, connected together to a length of twenty-six feet, and balanced vertically over the smelting furnace, so as to descend gradually with the charges of iron and fuel. The tube sank three feet per hour at first, and more slowly afterwards. The gases were conveyed by a leaden tube to a convenient position, where samples were sealed in glass tubes for experiment.

The furnace was supplied by a hot-blast, at a temperature of 626° Fahr., at a pressure of 6·75 inches of mercury. The charge consisted of 420 lbs. of calcined ironstone, 390 lbs. of coal, and 170 lbs. of limestone—the product of which is 140 lbs. of pig iron. The following results were obtained by eudiometric analysis, showing the percentage composition of the gases obtained at depths from the charging platform, varying from 5 to 34 feet:—

TABLE *of Analyses of Gases at Alfreton.*

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.
Depth under the top, in feet,..........	5	8	11	14	17	20	23	24	34
Nitrogen . . .	55·35	54·77	52·57	50·95	55·49	60·46	58·28	56·75	58·05
Carbonic acid, .	7·77	9·42	9·41	9·10	12·43	10·83	8·19	10·08	0·00
Carbonic oxide,	25·97	20·24	23·16	19·32	18·77	19·43	29·97	25·19	37·43
Light carburetted hydrogen	3·75	8·23	4·57	6·64	4·31	4·40	1·64	2·33	0·00
Hydrogen . .	6·73	6·49	9·33	12·42	7·62	4·83	4·92	5·65	3·18
Olefiant gas .	0·43	0·85	0·95	1·57	1·38	0·00	0·00	0·00	0·00
Cyanogen . .	0·00	0·00	0·00	0·00	0·00	0·00	trace	trace	1·34

The conclusions arrived at by Messrs Playfair and Bunsen, from a consideration of the above analyses, may be stated as follows :—1*st*, That light carburetted hydrogen being a product of distillation, the coking process extends to a depth of twenty-four feet in the furnace, and the process of distillation of the coal reaches its maximum at a depth of fourteen feet. The vapours of tar are decomposed in the upper part of the furnace. 2*d*, The quantities of carbonic acid and carbonic oxide are *not* mutually dependent. This is due to the subjection of the ore to a simultaneous process of *reduction* by the oxidation of the carbonic oxide, and of *oxidation* by the steam escaping from the coal. The gases could not be collected at a depth lower than the top of the boshes. If the reduction of the ore and evolution of carbonic acid from the limestone had been completely effected above the point of the furnace to which they reached, the gases formed below would have contained their nitrogen and oxygen in the same proportion as in air, or as 79·2 : 20·8.

It will be seen that this is not the case from the following table :—

Depth in feet .	5	8	11	14	17	20	23	24	34
Nitrogen . .	79·2	79·2	79·2	79·2	79·2	79·2	79·2	79·2	79·2
Oxygen . .	24·9	23·6	24·6	19·5	25·7	23·7	28·2	27·7	27·8

The constant proportion 79·2 to 27 at the 23 and 24 feet proves that in hot-blast furnaces fed with coal the reduction of the iron and the expulsion of the carbonic acid of the limestone takes place in the boshes of the furnace. This depression of the point of reduction so much lower than in the continental charcoal furnace Messrs Bunsen and Playfair attribute to the prolongation of the coking process, and the consequent reduction of the temperature in the upper parts of the furnace.

The following results have been obtained by Mr Ebelman, who has investigated the same subject with care, and do not agree strictly with those obtained by the English

	I.	II.	III.		IV.	V.	VI.	VII.
Depth from top in feet . .	$3\frac{3}{4}$	$3\frac{3}{4}$	$9\frac{3}{4}$	$9\frac{3}{4}$	$19\frac{1}{2}$	$19\frac{1}{2}$	27	Tymp.
Carbonic acid .	12·01	11·95	4·14	4·23	0·49	0·07	0·00	0·93
Carbonic oxide .	24·65	23·85	31·56	31·34	35·05	35·47	37·55	39·86
Hydrogen . . .	5·19	4·31	3·04	2·77	1·06	1·09	1·13	0·79
Carburetted hydrogen . .	0·93	1·33	0·34	0·77	0·36	0·31	0·10	0·25
Nitrogen . . .	57·22	58·56	60·92	60·89	63·04	63·06	61·22	58·17
Totals	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00
Oxygen per 100 nitrogen . .	42·5	40·8	32·7	32·7	28·5	28·2	30·7	35·8
Carbon vapour, per 100 nitrogen . .	32·8	31·7	29·6	29·6	28·5	28·5	30·7	35·9

chemists. The first results are from a charcoal furnace at Clerval, working with cold-blast under a pressure of 0·44 inches of mercury. The charges consisted of 253 lbs. of charcoal, 397 lbs. of ores, and 254 lbs. of limestone.* I. Gas taken a short time after charging. II. Gas taken a quarter of an hour after charging. III. Gas obtained through a four-inch cast-iron tube. IV. Gas obtained by boring the masonry. V. The same an hour after. VI. Gas obtained by boring the masonry 3½ feet above the tuyeres, and collected through porcelain tubes. VII. Gas obtained through gun-barrels lined with porcelain.

The above results show a progressive diminution of carbonic acid, and a similar increase of carbonic oxide, till at 27 feet from the top the former is entirely absent.

The following results were obtained at the coke furnace at Seraing, the blast being heated to 212°, and the charges

	I.		II.	III.	IV.		V.	VI.
Depth from top in feet	1	1	4	9	10	10	12	45
Carbonic acid	11·39	11·39	9·85	1·54	1·08	1·18	0·10	0·00
Carbonic oxide	28·61	28·43	28·06	33·88	35·20	35·35	36·30	45·05
Hydrogen	2·71	3·04	0·97	0·69	1·72	2·08	2·01	0·25
Carburetted hydrogen	0·20	...	1·48	1·43	0·33	0·29	0·25	0·07
Nitrogen	57·06	56·64	59·64	62·46	61·67	61·15	61·34	54·63
Totals	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00
Oxygen per 100 nitrogen	45·0	45·6	40·0	29·6	30·2	30·6	29·9	41·2
Carbon vapour, per 100 nitrogen	35·2	35·7	33·0	29·4	29·6	30·0	29·9	41·3

* Annales des Mines, vol. xix., 1851.

consisting of 1434 lbs. of unroasted ores, 1434 lbs. of forge cinders, 948 lbs. of limestone, and 1765 lbs. of coke:—

I. and II. Gas obtained through iron tube, about 1 inch diameter.

VI. Gas obtained by boring through the masonry 2 feet above the tuyeres.

This furnace was 50 feet high. Ebelman draws from his experiments the following general conclusions:—

That the amount of carburetted hydrogen in the furnace gases is too small to affect the chemical reactions in the furnace.

That the air thrown in produces successively carbonic acid and carbonic oxide at a small distance from the tuyere; the former attended by a disengagement of heat; the latter by a re-absorption of the principal part previously disengaged. The limits of the zone of fusion bear relation to this reaction.

The ascending current of carbonic oxide and nitrogen produces these effects: it heats the descending column of minerals; it becomes charged with volatile products disengaged from the fuel, the limestone, &c., and it reduces the oxide of iron to the metallic state.

The zone in which carbonic oxide exists alone is much more extended in coke than in charcoal furnaces.

The discordance between these results and those obtained by Messrs Bunsen and Playfair, is attributed by Mr Ebelman to the employment by the former of long and narrow iron tubes for collecting the gases, which, becoming intensely heated, and charged with dust projected into them by the blast, modified the constitution of the escaping gases.

Utilisation of the Waste Products of the Blast Furnace.—The above investigations of Messrs Bunsen and Playfair led them to the conclusion that in the furnaces at Alfreton 81·5 per cent. of the fuel is lost in the form of combustible matter still fit for use, or that 11·4 tons of coal are wasted in the twenty-four hours; and that these gases were capable of generating a temperature by their combustion sufficient to melt iron.

In consequence, very many attempts have been made to collect these and apply them to useful purposes in generating steam, or heating the hot-blast oven, and to prevent their useless dissipation in the atmosphere. Proposals of this kind were made as early as the latter part of the eighteenth century, as is shown by the records of the Patent Office. Perhaps the earliest rational plan of this kind was that of Meckenheim in 1842, who proposed to draw off the gases by pipes placed 10 or 15 feet below the tunnel-head, the compression of the blast being sufficient to force them into the pipes. This plan, with various modifications, has since been successfully adopted, the pressure of the gases beneath the surface of the materials having been found by Bunsen and Playfair to be—

	Column of Water.		Column of Water.
At 5 feet	= 0·12 inch.	At 20 feet	= 1·80 inch.
8 „	= 0·40 „	23 „	= 4·70 „
11 „	= 1·10 „	24 „	= 5·10 „
14 „	= 1·60 „		

To enable the waste gases to be collected and applied to raising steam, heating hot-blast stoves, &c., without detriment to the working of the blast furnace, it is necessary to withdraw them at an elevation where they have completed their work, yet at such a distance from the

mouth of the furnace that they may be extracted in a dry state, and before they come into contact with the atmosphere, so as to cause combustion. This may be effected, either by increasing the height of the blast-furnace, withdrawing a portion of the gases through apertures in the side, or, if the furnace be not too large, by closing the top of the furnace with a moveable door. Fig. 20 shows the first plan; AA are the apertures through which the gases escape by the chamber BB into the pipe C, which conveys them to the place where they are burnt.

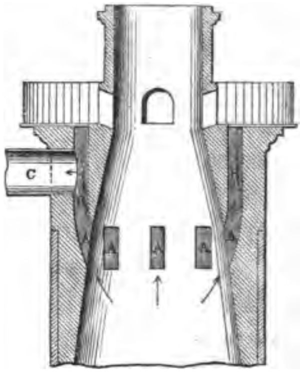


Fig. 20.

The requisite pressure for causing the gases to escape at AA is obtained by heaping the charges of fuel and ore to some height above them, and narrowing the upper part of the furnace. To prevent the admixture of atmospheric air, and the consequent ignition of the gases before their arrival at that point where their heat is to be utilised, the openings should be 10 or 15 feet below the surface of the materials. In this way a sufficient pressure is obtained to force the gases into the annular chamber BB, and through the pipe C. Fig. 21 shows another contrivance for the same purpose. A cast-

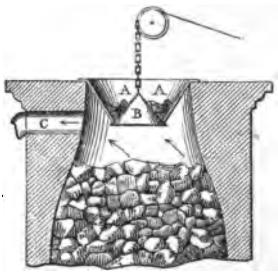


Fig. 21.

ing AA, in the shape of a truncated cone, is fixed at the top of the furnace, the small diameter downwards; the aperture in the bottom of this is closed by another conical casting B, supported by a chain and counterpoise weight; this evidently shuts the mouth of the furnace, and the gases pass off by the pipe C. When a charge is to be thrown in, it is emptied into the cone hopper AA. When the charge is complete, the moveable cone B is lowered so as to enable the charge to pass between it and the edges of the hopper, when it is again raised, and the operations of the furnace proceed as before. This method of distributing the materials towards the periphery of the furnace is said to be favourable to its working, and the plan of closed tops has been most successful in South Wales. The gases are conveyed away by a three-feet or four-feet pipe, supplied with large valves to prevent danger from explosion, and applied either to heating the boilers of the blowing-engine, or to heating the blast.

In this country sufficient attention has not been paid to this economical practice, as compared with what has been done in other countries where fuel is expensive. It is no excuse that fuel is cheap, as in most cases the gases can be applied with economy, and their combustion tends to abate the serious nuisance of smoke. When first attempted in Staffordshire, the means adopted so altered the working of the furnaces, and caused so much irregularity, that the plan was abandoned. Mr Blackwell, who has very successfully utilised the gases in some cases, records an instance of the way in which this happened. In 1852 a furnace was placed under his direction, from which the gases were taken off for heating the blast, in

which he adopted a plan similar to that shown in fig. 21. The furnace with this arrangement worked regularly, and carried a good burden; but white iron alone was produced. The burden was lightened, but the iron remained white. A yet further lightening of the burden was made; but, although the cinder was exceedingly grey, still the iron was white. It became evident that a still greater proportion of coke would not produce the desired effect, and was, in fact, useless. The white iron was the effect of the closed top. It was found necessary to sacrifice the gases for the production of grey iron. The white iron had been caused by the pressure produced by the closed top, to which the furnace was most sensitive. But, on the whole, no plan is so effective, or so little interferes with the working of the furnace, as that generally employed in South Wales, and shown in fig. 21.

It should also be stated, that in those furnaces in which coke is employed the waste gases may in a similar manner be rendered useful, by conducting the coking process in close ovens, and conveying the liberated gases to the steam-boilers, in place of the ordinary wasteful method of coking in the open air in large heaps.

The crude pig-iron produced in the smelting furnace is assorted according to the degree and uniformity of its carburisation, and is classed by the ironmaster as No. 1, 2, or 3, according to the amount of carbon it contains. No. 1 is most highly carburised, No. 2 less so, and so on to a No. 4, iron which is sometimes produced. The carbon combined with the iron gives it fusibility, but deprives it of ductility. To render it malleable and capable of being welded, it must be deprived, as far as possible, of

all extraneous substances which have been mixed with it in the blast-furnace, more especially of carbon.

The carbon exists in the cast-iron in two forms; it is either combined with the iron chemically, or it is mechanically mixed with it in graphitic scales, which can be perceived with a microscope. The amount of carbon in cast-iron varies from 2 to 4 per cent.; of this the greater part is graphitic in grey iron; in mottled iron it is partly combined, partly graphitic; and in white iron it is wholly combined. Usually white iron contains less carbon than grey; but this is not a constant characteristic.

Manganese is present in cast-iron, being reduced in the smelting process to the extent of from 0·7 to 4 per cent., and on the average 2 per cent. A part of the silica of the ores is also reduced, and appears to form an alloy with the iron. The amount of silicium varies between the limits of 0·3 and 3 per cent., and appears to be greater in hot than cold blast iron.

The sulphuret of iron in the ores and fuel is partly decomposed and carried of by smelting as sulphuret of calcium, and partly remains in the iron, rendering it redshort and injuring its tenacity. Mr Calvert, of Manchester, has proposed to eliminate this injurious constituent by the use of chlorides (by preference common salt) in the coking and calcining or smelting processes. Chloride of sodium has been used for a similar purpose in the puddling process in Belgium. The amount of sulphur varies up to 0·1 per cent., and in some cases to 1 per cent.

Phosphorus in the ores or fuel passes mostly into the cast-iron, and has a most pernicious effect. It is believed

to render the iron cold-short. Its amount varies up to 1·5 per cent.

Arsenic, aluminium, calcium, magnesium, sodium, potassium, and a few other metals, are occasionally found in cast-iron; but their influence on its strength and other properties is very little understood.

To prevent the contamination of the crude metal by the impurities of the fuel employed, Dr Gurlt, of Prussia, has proposed a system of smelting similar in principle to that of the Silesian puddling furnaces, which will be described in the next chapter. He proposes to convey the roasted ore, after crushing, into a cupola, the lower portion of which communicates with two close ovens or gas generators, in which any kind of fuel is submitted to a slow process of distillation and imperfect combustion, so as to produce carburetted hydrogen, carbonic oxide, &c. These gases, on passing into the cupola, are ignited by contact with a stream of air supplied by a blast, and the heat is raised to a temperature calculated to effect the reduction of the ores. In this way the iron is smelted without ever coming in contact with the impurities of the fuel. The subject is an important one, as there are abundance of spathic, hæmatite, and specular ores to supply a very fine quality of iron, if they could be reduced without being contaminated by the unavoidable impurities of coal, coke, or limestone. A great deal has yet to be accomplished in this way, and the subject is well entitled to the close attention of our best analytical chemists.

CHAPTER V.

THE CONVERSION OF CRUDE INTO MALLEABLE IRON.

THE conversion of the carburised crude iron, obtained from the blast-furnace, into malleable or wrought iron, is effected by several operations of an oxidising character, in which it is sought to separate, in the gaseous state, the carbon contained in the iron, by combining it with oxygen, whilst the other metals alloyed with the iron, and the phosphorus, pass into the slag.*

Methods of Conversion with Charcoal and Coke Iron.—In reference to subsequent operations, the iron produced in the smelting furnace may be divided into two kinds—that reduced by charcoal, and that reduced by coke or raw coal. When charcoal iron has to be converted by charcoal, as in Sweden, it is decarburised in the charcoal refinery, with or without an intervening process. Where coal can be obtained, however, it is now usually converted by the process of puddling. Pig-iron produced by coke or coal is converted into malleable iron either by decarburisation in the refinery or oxidising hearth, and subsequent puddling, or it is converted at once in the pud-

* See Mr Blackwell's paper, On the Iron Industry of Great Britain, read before the Society of Arts.

dling furnace by the process of boiling, which is equally effective, and is now more generally practised.

This last process, as the one most generally adopted in this country, deserves a special notice, and we are fortunate in having before us the particulars of the manner in which it is conducted by Messrs Rushton and Eckersley of Bolton, kindly furnished by Mr Rushton, the senior partner of the firm. This establishment is probably one of the most modern and complete of the kind in the kingdom; it is one that has spared no expense in the application of useful inventions, and has kept pace with every improvement that has taken place in the manufacture of bar and plate iron for the last fifteen years.

The machinery and appliances at these works consist of—

6 Steam-engines, of 180 total nominal HP.
2 Five-ton and 2 fifty-cwt. steam-hammers.
3 Helve-hammers.
1 Set of puddled iron rolls.
1 Set of boiler-plate rolls.
1 Merchant train and balling mill.
16 Puddling furnaces.
14 Balling and scrap furnaces.
And other machinery, such as plate and bar shears, lathes, &c.

Since in all processes of converting, the carbon of the crude metal has to be oxidised and got rid of, *primâ facie*, it would appear that whilst the highly carburised pig-iron is the most suitable for casting, that containing least carbon is best adapted for conversion into malleable iron; hence, in the trade, the crude iron is divided into foundry and forge pigs.

The pigs, however, in which carbon most predominates,

and which, as a rule, have been least contaminated with *other* impurities during the process of smelting, are in many respects preferable for the manufacture of wrought-iron; up to this time, however, great practical difficulties have attended the decarburisation of iron containing so much carbon, and the white or forge iron is almost always preferred, measures having been taken for depriving it of the metals and earthy impurities not separated in the blast furnace.

The Refining Process.—With regard to the process of refining, we may observe, that the crude iron is melted in a hollow fire, and partially decarburised by the action of a blast of air forced over its surface by a fan or blowing engine. The carbon having a greater affinity for the oxygen than for the iron, combines with it, and passes off as gaseous carbonic oxide or carbonic acid. During this process, a portion of the silicum, &c., is fused out, and separated from the iron. It is obvious from the above that the iron to be refined, being placed in contact with fuel at a high temperature, is liable to be deteriorated by the admixture of sulphur and other impurities of the fuel; and as the iron is only partially exposed to the action of the blast, the operation is necessarily, under these circumstances, imperfect. From the refinery the metal is run out into large moulds, and is then broken up into what is technically distinguished as "*plate metal.*"

Mr Clay has tried with some success a process of refining, in which the molten crude iron is allowed to fall in minutely divided streams from the top of a tower constructed on the principle of those in which lead is granulated for shot. The carbon is effectually burned off dur-

ing its fall, owing to the minutely divided condition of the metal, and it is further purified from sulphur and phosphorus by being received in a vessel of water.

The Puddling Process.—The process of puddling succeeds that of refining; and in this operation the reverberatory furnace is employed, with the fire separated by a partition or bridge from the hearth, on which is placed the metal to be puddled. By this arrangement the flame is conducted over the surface of the metal, creating an intense heat, though the deleterious portions of the fuel cannot mix with the iron. Fig. 22 shows the form of the reverberatory furnace in section. It consists externally of an oblong casing of iron plates, firmly bound together by iron tie-bars, and lined with fire-brick. A is the fire grate, separated from the body of the furnace E by a bridge, over which the heated products of combustion, with a surplus of oxygen, play upon the surface of the molten metal, and effect its conversion, and thence pass to a lofty chimney K, over the top of which is suspended a metal plate, by which the draught can be regulated to a nicety. The body of the furnace E is dish-shaped, and constructed of cast-iron plates, the sides being in some cases hollow blocks, through which a stream of water or air is made to circulate to retard their deterioration by the heat. The free access of air to the under side of the plate forming the bottom, in a similar manner conserves that part. The puddler effects his operations through a door balanced by a lever and weight, so as to open or close with ease. In some furnaces the charge of iron, weighing about 4 cwts. before its introduction into the puddling furnace, is raised to a red heat in a

chamber provided for that purpose between the body of the furnace and the chimney, and in this way both time

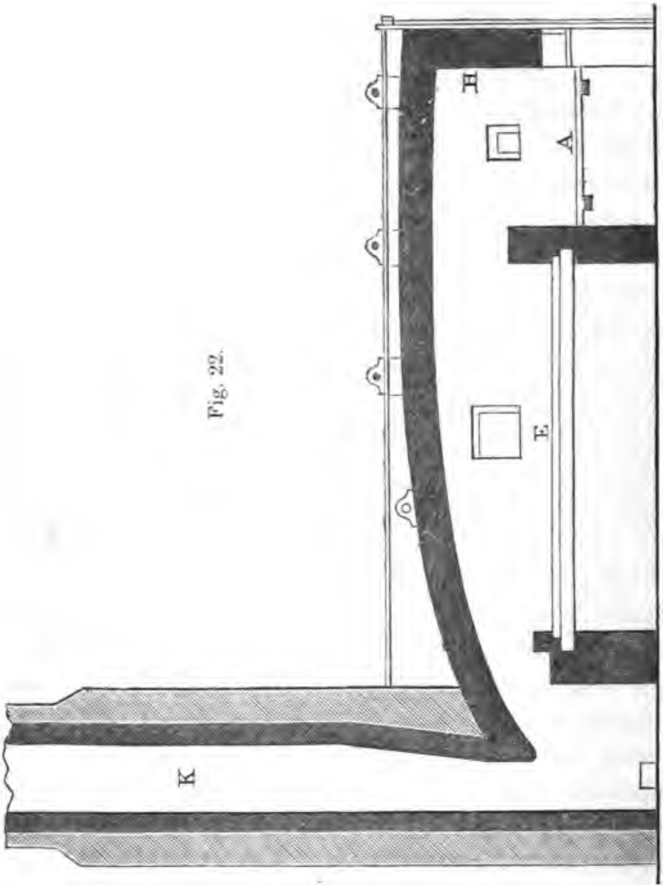


Fig. 22.

and fuel are economised. In the furnace the iron is kept in a state of fusion, whilst the workman, called the "puddler," by means of a rake or *rabble*, agitates the metal so

as to expose, as far as he is able, the whole of the charge to the action of the oxygen passing over it from the fire. By this means the carbon is oxidised, and the metal is gradually reduced to a tough, pasty condition, and subsequently to a granular form, somewhat resembling heaps of boiled rice with the grains greatly enlarged. In this condition of the furnace, the cinder or earthy impurities yield to the intense heat, and flow off from the mass over the bottom in a highly fluid state.

At intervals in the process, portions of oxides of iron, hammer scales, scoriæ, and in some cases limestone and common salt, are thrown upon the molten iron, and form a fluid slag, which assists in oxidising the carbon, and removing as silicates, &c., the magnesia, sulphur, and other impurities of the iron.

The iron at this stage is comparatively pure, and quickly becomes capable of agglutination; the puddler then collects the metallic granules or particles with his *rabble*, and rolls them together, backwards and forwards, over the hearth, into balls of convenient dimensions (about the size of thirteen-inch shells), when he removes them from the furnace to be subjected to the action of the hammer or mechanical pressure necessary to give to the iron homogeneity and fibre. This double process of refining and puddling has universally been employed till recently; but improvements have rendered it simpler, and the refining process is now very generally abolished.

The Boiling Process.—Shortly after the employment of the puddling process, it was found advantageous to mix a portion of crude iron with the refined plate metal, the expense of the process of refining being saved upon the

iron used in the crude state; and trusting to the decarburising effects of the puddling furnace, it was found that the refining process may be altogether dispensed with, if crude iron containing a proportion of oxygen and very little carbon was employed. In this single process it is to be observed, that as all the carbon has to be got rid of in the puddling furnace, the evolution of gas is much more violent, the fluid iron boiling and bubbling energetically during the period of its disengagement; and hence the operation has acquired the popular name of the "boiling" process.

In this operation the pig-iron when melted is more fluid, on account of containing a greater proportion of carbon than the metal from the refinery, and requires more labour in stirring it about and submitting it to the action of the current of air; the process, moreover, is attended by a greater waste of iron than puddling either plate or crude iron and plate mixed, but not so great a loss as in the two operations of refining and puddling. It must, however, be admitted that the superior fluidity of the iron in the boiling process has a more injurious action on the furnace. Notwithstanding these objections, the system of boiling without the intermediate process of refining has been gaining ground for the last ten years, and in many places has entirely superseded the use of the refinery; recent events have therefore led to the conclusion, that in a short time the refining process will have become a thing of the past.

At Messrs Rushton and Eckersley's works, a small proportion of Cumberland hæmatite ore, or peroxide of iron, is mixed with the pig iron to be converted, as it is found

to assist in the process of boiling by supplying oxygen in the molten mass, and in other respects facilitating the process, and increasing the yield and improving the quality of the metal.

Numerous attempts have been made to secure a more scientific and perfect decarburisation of the crude iron, but without success. One improvement, however, patented in 1854 by Mr James Nasmyth, gives promise of making the boiling process as nearly perfect as we may hope to see it. It has been in use for two years at the Bolton Iron-Works, and from its constant employment in the puddling furnaces of that establishment, it has given direct proof of its utility, and is gradually extending itself among the large manufacturers as its advantages become known.

The invention consists of the introduction of a small quantity of steam, at about 5 lbs. pressure per square inch, into the molten metal as soon as it is fused. As the oxygen of the steam has at that high temperature a greater affinity for carbon than for the hydrogen with which it is combined or for the iron, the carbon is rapidly oxidised off. The liberated hydrogen has no affinity for the iron, but unites with sulphur, phosphorus, arsenic, &c.—substances very injurious to the quality of the iron, if present even in minute quantities, and yet frequently found in the ores and fuel.

The steam has also a mechanical as well as a chemical action on the iron. Being introduced at the bottom of the furnace, and thence diffused upwards, it violently agitates the iron, and causes the exposure of fresh surfaces to the oxygen passing through the furnace.

The mode of operating is as follows:—The steam is conveyed from the boiler to a vertical pipe fixed near the furnace door, having at its lower end a small tap or syphon, to let off the condensed steam, and prevent its being blown into the furnace. A cock with several jointed pieces of pipe are fastened to the flange of the vertical pipe, so as to form, as it were, jointed bracket pipes, somewhat similar to those of gas pipes, which allow free

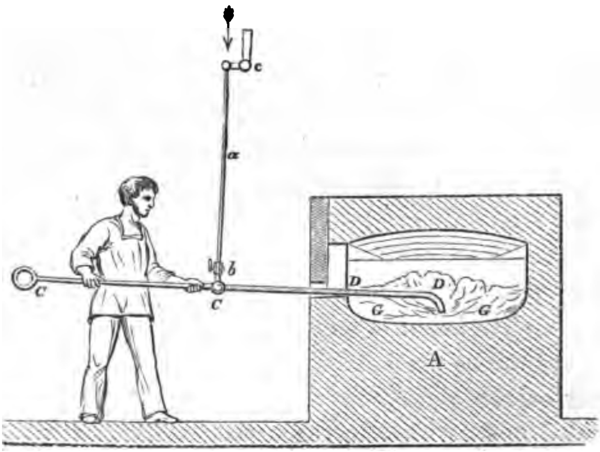


Fig. 23.

motion in every direction, as in the annexed sketch, in which A, fig. 23, is the reverberatory furnace, *a* the vertical steam pipe communicating with the boiler, *b* the tap or steam cock, *cc* the elbow-jointed tubes, CC the handle, and DD the steam tube or rabble, bent at the end, so as to inject the steam on the liquid metal GG. This apparatus is introduced into the furnace immediately the iron is melted, the puddler moving it slowly about in the molten iron, while the steam pours upon it through the

bent end of the tube. In the course of from five to eight minutes the mass begins to thicken, the steam pipe is withdrawn, and the operation finished in the ordinary way with the common iron *rabble*. The time saved by this process in every operation, or *heat*, as it is technically called, averages from ten to fifteen minutes, and that during the hottest and most laborious part of the operation.

By means of this apparatus, the highly carburised pig iron, which is the most free from impurities, is rendered malleable in one furnace operation, without the deteriorating adjuncts of the refining and puddling process as ordinarily practised; in this operation no deleterious substance can combine with the iron, whilst in the refinery process the mixture of the fuel and metal is liable to deteriorate the latter with sulphur, silicum, &c. This new process, it is affirmed, has a beneficial effect in purifying the iron with greater economy and rapidity than any other process with which we are acquainted.

Silesian Gas Puddling Furnaces.—Irrespective of the improvements just described, there is another which is extensively used on the Continent, denominated the Silesian gas furnace. For a drawing and explanation of this furnace we are indebted to Mr Anderson, inspector of machinery at the arsenal, Woolwich. The following drawing, fig. 24, will explain the new Silesian furnaces which are used in the manufactnre of iron in that country, in place of our reverberatory air furnaces, and are said, on good authority, to be a very great improvement, not only in regard to the entire prevention of smoke and the economy of fuel, but also in simplifying the wrought-iron

manufacture, and enabling a less skilled class of workmen to manage the furnaces.

Their general character is that of a reverberatory furnace, the fireplace of which is replaced by an oblong chamber, 4 feet by 6 feet, and denominated the Gas-generator, which may be described as a close brick chamber with an opening at the bottom for the admission of air from a fan, by means of which the gases are driven out of the chamber into the furnace amongst the iron to be heated. At the point where the gases enter the furnace, a series of tuyeres are provided for the admission of air from the same fan. The pipes that convey the air and the gas from the retort to the tuyeres are both provided with valves, in order that the attendant may modify the quantity from either source, so as to obtain any intensity of flame the work may require, and also to produce perfect combustion, thus placing the entire action of the furnace under complete control. It is about eleven years since these furnaces were first introduced; and notwithstanding the prejudices that were naturally raised against them, they are said to be now extensively adopted in the Silesian district, and in great favour with both the master and the workmen.

In this description of furnace there appear to be four great advantages over the air-furnace—

1*st*, The entire absence of smoke, in consequence of complete combustion.

2*d*, The saving of upwards of 33 per cent. in fuel, from the whole of the gaseous products being made available, and there being no necessity for the flame to pass up the chimney to produce draught, as in the case of the reverbe-

ratory furnace, which requires an inordinate supply of fuel as compared with what is wanted to work the fan.

3*d*, The absolute control the attendant has over the furnace, as regards the temperature and the simplicity with which it can be worked. Its operations in this respect are, according to those who have seen it at work, so perfect as to be as precise in its action as a machine.

4*th*, The iron is preserved from contact with the ash and impurities of the fuel.

Mr F. A. Abel, who saw these furnaces at work at the Government Iron Works in Upper Silesia, describes the process of refining in the following way: When the charge of iron on the hearth is ascertained to be thoroughly fused, a small quantity of crushed limestone is thrown over its surface, and two tuyeres are then introduced into the furnace at an angle of 25° through an opening on each side of the hearth, not far from the bridge. The width of the nozzle employed depends on the power of the blast used; the air rushing from these tuyeres impinges with violence on the iron, and, the two currents meeting, an eddying motion is imparted to the fused metal. In a short time the motion produced in the mass is considerable; the supernatant slag is blown aside by the blast, and the surface of iron thus exposed undergoes refinement, while it changes continually, the temperature of the whole mass being raised to a full white heat by the action of the air. The iron is also stirred occasionally, in order to insure a proper change in the metal exposed to the action of the blast. A shovelful of limestone is occasionally thrown in, the total quantity used being about 1 per cent. of the iron employed. The duration of the treatment in this furnace

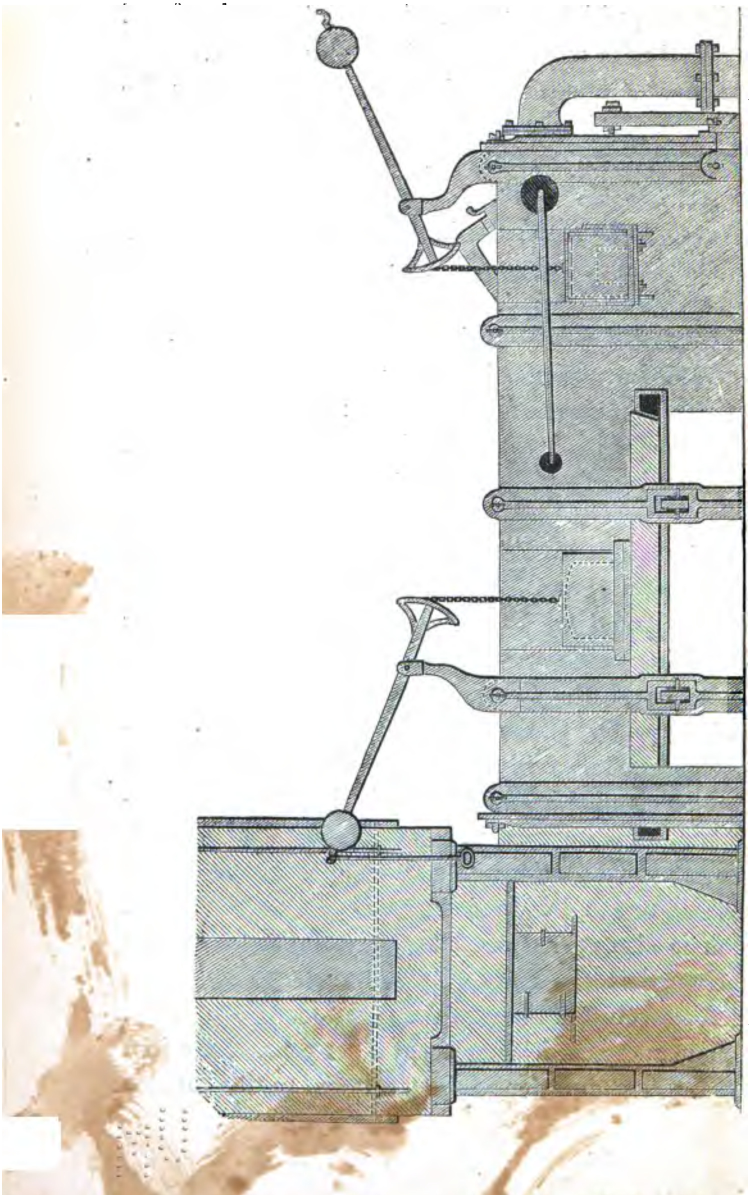


Fig. 24.—Silesian Gas Furnace.

after the fusion of the metal, with a charge of 40 cwt., varies from two and a half to five hours, according to the produce to be obtained. When the charge is to be withdrawn from the furnace, the side tuyere nearest the tap-hole is removed, so that the blast from the opposite tuyere may force the metal towards the hole. The fluid iron, as it flows from the tap-hole, is fully white hot, and perfectly limpid. It chills, however, very rapidly, and soon solidifies.

From this description it would appear that the iron-masters of this country have not made themselves acquainted with these improvements; but having some knowledge of the efficiency and existence of this process, we would earnestly recommend it to their attention, as an invention in more respects than one entitled to consideration.

CHAPTER VI.

THE MECHANICAL OPERATIONS OF THE WROUGHT-IRON MANUFACTURE.

THE mechanical operations connected with the manufacture of wrought-iron consist of shingling, hammering, rolling, &c., to which we may add the forging of "*uses*," that is, the forging of those peculiar forms so extensively in demand for steam-engines, steam-boats, railway carriages, and other works, which has lately become a large and important branch of trade.

In tracing the whole of the processes in the manufacture of wrought-iron bars and plates, it will not be necessary to enlarge on those practices which have been superseded by more modern and improved machinery. Suffice it then to observe, that the puddled balls have to be *shingled* or fashioned into oblong slabs or *blooms* by the blows of a heavy forge-hammer. During this operation, the scoriæ and impurities which adhere to the balls are separated from the blooms by the force of impact, and then by a series of blows the iron is rendered malleable, dense, and compact. The blooms are then passed through a series of grooved iron rollers, which reduce them to the form of long, slender iron bars, called puddle bars. These are cut up and piled regularly together or *faggotted*, and brought to a welding heat in the heating or *balling* fur-

nace, when they are again passed several times through grooved rollers, and by this latter process are made into bars or plates ready for the shears.

In order to arrive at a clear conception of the mechanical operations employed in the manufacture of iron, it will be necessary to describe more at length the processes as at present practised, with the improved and powerful machinery now employed; and as much depends upon the application of the motive power, the steam-engine claims the first notice. Until of late years, the vertical steam-engine was invariably used for giving motion to the forge-hammer and rolling-mill, which were placed on one side of the fly-wheel and the crank on the other; but the high-pressure non-condensing engine is found to be decidedly preferable, as the waste heat passing off with the products of combustion from the puddling and heating furnaces is quite sufficient to raise the steam for working the rolls and one of Brown's bloom squeezers, as shown in the following drawing.

In this arrangement the cylinder A (figs. 25 and 26), is placed horizontally, and is supplied with steam from boilers near the puddling furnaces. The piston rod and slides B, and connecting rod C, give motion to the crank shaft D, on which is fixed a heavy fly-wheel E. The puddling rolls F F are driven direct from the end of the fly-wheel shaft, being attached to it by a disengaging coupling C; the bloom-squeezers H are driven by a train of spur wheels G G. Under the lower rolls of the squeezers a Jacob's ladder or elevator I is fixed, for raising the block which has been deprived of its impurities, and reduced to an oblong shape by passing between the rollers

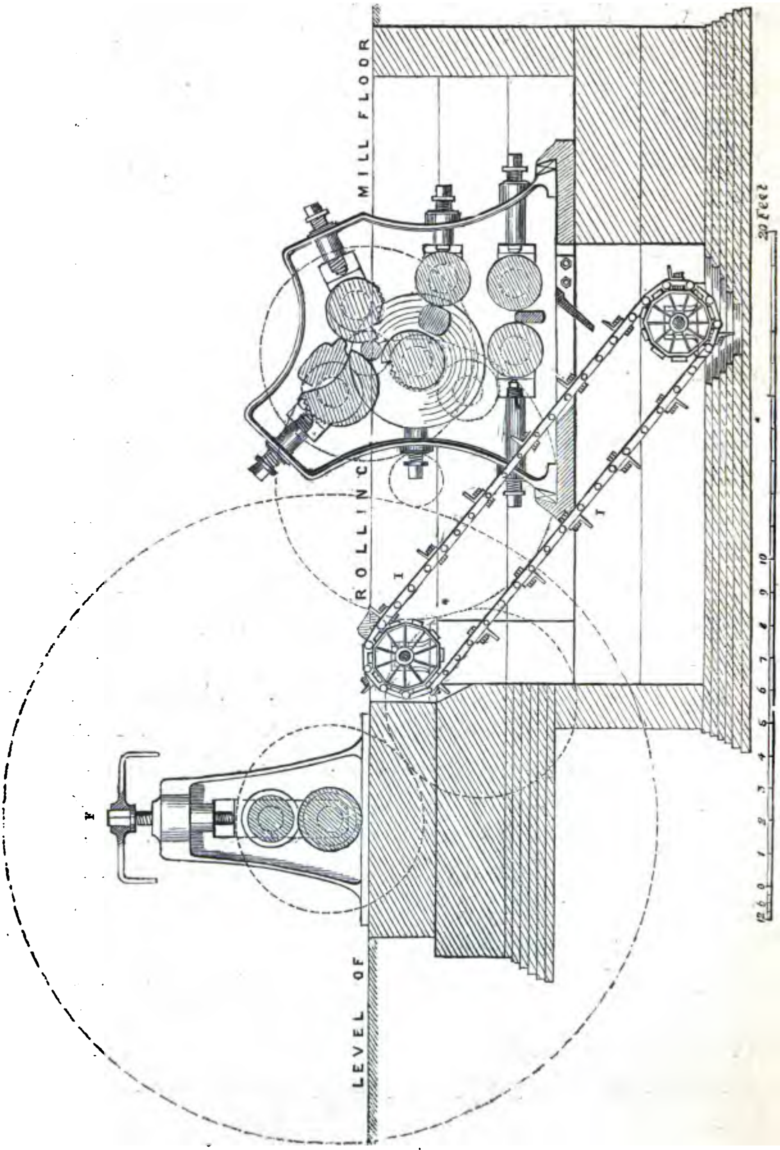


Fig. 26.—Arrangement of Rolling-mill.

of the squeezer. The block, on leaving the rollers, is carried in front of one of the projecting divisions of the ladder I, and thrown on to the platform in front of the rolls F F; the workman then seizes it with a pair of tongs, and forces it into the largest groove in the rolls; it is then passed in succession through the other grooves till it attains the required form of the bar.

Shingling.—The old method of shingling the puddle balls, and one still much practised from its simplicity, was to reduce them to shape by a heavy hammer called the forge-hammer or helve, shown in fig. 27. It consists

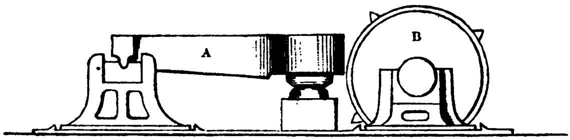


Fig. 27.

of a heavy mass of iron, A, resting on a pivot at one end, and lifted by projecting cams on a revolving wheel, B, at the other; between these points, and nearer the front, is the anvil, on which the puddler's ball is thrown to receive a rapid succession of strokes, which force out the impurities, and reduce it to a form suitable for insertion between the rolls.

The *squeezer* has also been used for the same purpose, consisting of two massive jaws worked by a lever and crank, between which the ball is moulded by severe pressure to the necessary form. The squeezer is, however, alleged to have the effect of lapping up cinder in the iron to a greater extent than in the case of the forge-

hammer. Fig. 28 shows one form of this instrument, sometimes called the Alligator, from its resemblance to

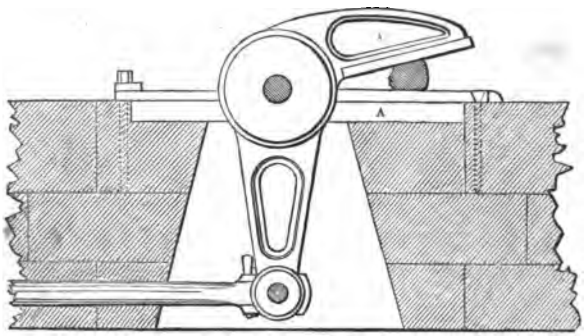


Fig. 28.

the mouth of that animal, where it will be observed that the puddle ball is reduced in size by being rolled by the puddler to the back part of the jaws, where the leverage is more powerful, as its diameter decreases.

One of the most perfect machines of this class is Brown's bloom-squeezer already alluded to, and shown in figs. 29, 30, and 31, which sufficiently explain how the heated ball of puddled iron, K, thrown on the top, is gradually compressed between the revolving rollers as it descends, and at last emerges at the bottom, where it is thrown on to the moveable "Jacob's ladder," I, fig. 26, by which it is elevated to the rolls, as already described. This machine effects a considerable saving of time; it will do the work of twelve or fourteen furnaces, and may be kept constantly going as a feeder to one or two pair of rollers. There are two distinct forms of this machine—one as shown in fig. 29, where the bloom receives only two compressions; and the

other, which is much more effective, where it is squeezed four times before it leaves the rolls and falls upon the Jacob's ladder, as exhibited in figs. 30 and 31.

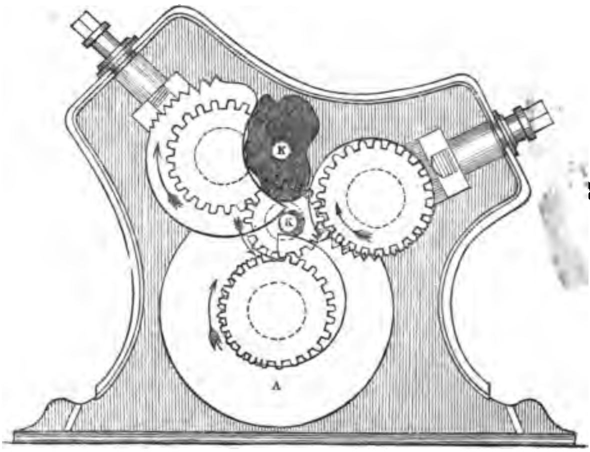


Fig. 29.

There is another machine for preparing the blooms by compression, namely, a table firmly embedded in masonry, as shown at A A, in fig. 32, with a ledge rising up from it to a height of about two feet, so as to form an open box. Within this is a revolving box C, of a similar character, much smaller than the last, and placed eccentrically in regard to it. The ball or bloom D is placed between the innermost revolving box C and the outer case A A, where the space between them is greatest, and is carried round till it emerges at E, compressed and fit for the rolls.

The bloom, after leaving the hammer or squeezer, is at once placed in the rolling-mill (fig. 33). This consists

of massive grooved rollers connected by toothed pinions, and put in motion by the steam-engine. The rollers are fixed on massive framing, which has to support a pro-

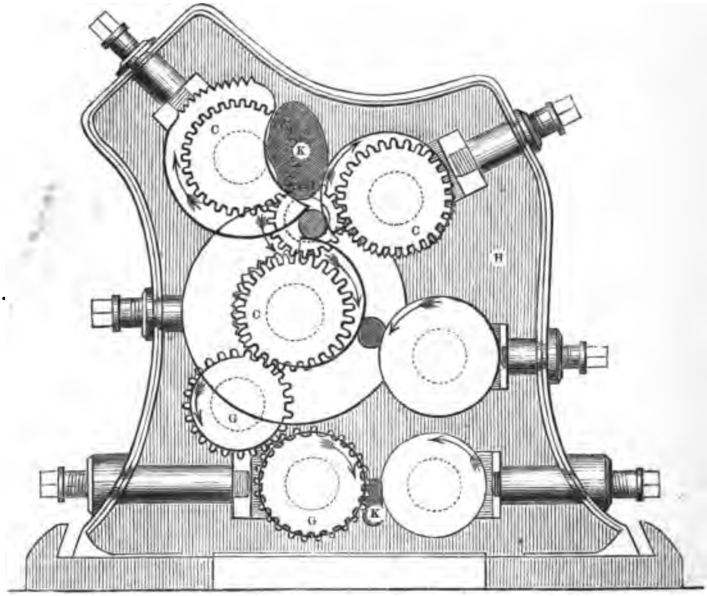


Fig. 30.

digious strain, as the bloom is sucked in, and compressed and elongated as it passes through. The bar so formed is passed through a succession of similar grooves, decreasing in size till it is reduced to about four inches wide, three quarters of an inch to an inch thick, and ten or twelve feet in length. In this state it is called a puddle-bar, and is taken to the shears, cut into pieces, piled into a second bloom or pile as it is then called, heated in a reverberatory furnace to a welding temperature, brought under the hammer, and a second time rolled. The bars

produced by this second process are called merchant-bars; or the bloom may have been rolled into plates; or lastly, instead of being rolled at all, it may have been brought

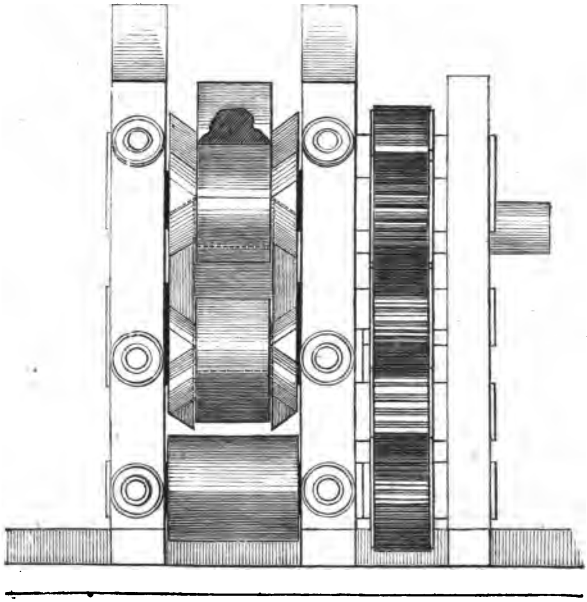


Fig. 31.

under the steam-hammer and forged into "*uses*," or those variously shaped masses of wrought-iron which are employed by the engineer and millwright.

Advantages of the Horizontal Engine.—We have stated that the horizontal, non-condensing steam-engine, from its compact form and convenience of handling, is admirably adapted for giving motion to the machinery of iron-works. For this object it is superior to the beam-engine, as its speed can be regulated with the greatest nicety, by opening or shutting the valve, so as to suit all the require-

ments of the manufacture, under the varied conditions of

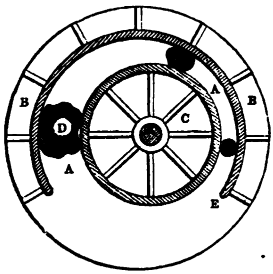


Fig. 32.

the pressure of the steam, and the power required for rolling heavy plates or bars, or those of a lighter description. It is also much cheaper in its original cost, and all its parts being fixed upon a large bed-plate, requires a comparatively small amount of masonry to render it solid and secure.

Rolling-mills.—In regard to the manufacture of the rollers for the puddling, boiler-plate, and merchant train, the greatest care must be observed in the selection of the

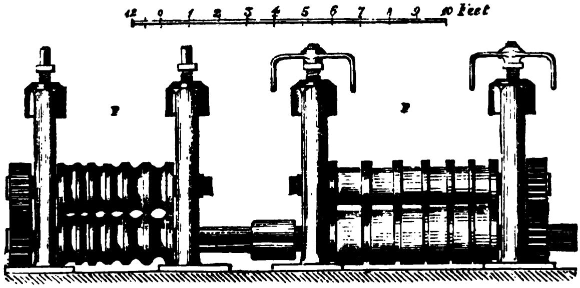


Fig. 33.

iron and the mode of casting. In Staffordshire there are roller-makers, but in general the manufacturer casts his own; and as much depends upon the metal, the strongest qualities are carefully selected and mixed with Welsh No. 1 or No. 2, and Staffordshire No. 2. This latter description of iron, when duly prepared, exhibits great tenacity, and is well adapted, either in the first or second melting, for such a purpose. In casting, the moulds are prepared in loam, and when dry are sunk vertically into

the pit to a depth of about five feet below the floor. The moulding-box is surrounded by sand firmly consolidated by beaters, and a second mould or head is placed above it, which receives an additional quantity of iron to supply the space left by shrinking, and keep the roll under pressure until it solidifies, and thus secures a great uniformity and density in the roller. The metal is run into the mould direct from the air furnace by channels cut in the sand; and immediately the mould is filled, the workman agitates the metal with a rod, in order to consolidate the mass and get rid of any air or gas which may be confined in the metal. This stirring with iron rods is continued till the metal cools to a semifluid state, when it is covered up and allowed slowly to cool and crystallize. This slow rate of cooling is necessary to favour a uniform degree of contraction, as the exterior closes up like a series of hoops round the core of the casting, which is always the most porous and the last to cool. In every casting of this kind, it is essential to avoid unequal contraction; and this cannot be accomplished unless time is given for the arrangement of the particles by a slow process of crystallization. Rollers for boiler-plates and thin sheet-iron are difficult to cast sound, on account of their large size. They are subjected to very great strain, and require to be cast from the most tenacious metals. The bearings or neck should be enlarged, or turned to the shape shown at A A, and the cylindrical part B, for plate-rolls, should be slightly concave; because, when the slab is

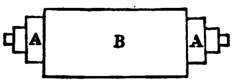


Fig. 34.

first passed through the rollers, it comes in contact with a small portion only of the revolving surface. The central

parts of the roller thus become highly heated, whilst their extremities are perfectly cool. The consequence is, that the expansion of the roller is greatest in the middle; and unless this be provided for by a concavity in the barrel, the plates become buckled, that is, both warped and uneven in thickness, and, consequently, imperfect and unfit for the purposes of boiler-making. Bar rolls are generally cast in chill, and great care is required to prevent the chill penetrating too deep, so as to injure the tenacity of the metal and render it brittle.

There are different kinds of rolling-mills used in the iron manufacture, and they vary considerably in their dimensions, according to the work they have to perform. The first, through which the puddled iron is passed, we have already described as puddling-rolls. There are others for roughing down, which vary from 4 to 5 feet long, and are about 18 inches diameter; those for merchant-bars, about 2 feet 6 inches to 3 feet long, and 18 inches in diameter, are in constant use. The boiler-plate and black sheet-iron rolls are generally of large dimensions; some of them for large plates are upwards of 6 feet long and 18 to 21 inches in diameter; these require a powerful engine and the momentum of a large fly-wheel to carry the plate through the rollers; and not unfrequently when thin wide plates have to be rolled, the two combined prove unequal to the task,—and the result is, the plates cool and stick fast in the middle. The greatest care is necessary in rolling plates of this kind, as any neglect of the speed of the engine or the setting of the rolls results, in the breakage of the latter, or bringing the former to a complete stand.

The speed of the different kinds of rolling-mills varies according to the work they have to perform. Those for merchant bars make from 60 to 70 revolutions a minute, whilst those of large size, for boiler-plates, are reduced to 28 or 30. Others, such as the finishing and guide rollers, run at from 120 to 400 revolutions a minute. In Staffordshire, where some of the finer kinds of iron are prepared for the manufacture of wire, the rollers are generally made of cast-steel, and run at a high velocity. Such is the ductility of this description of iron, that in passing through a succession of rollers, it will have elongated to ten or fifteen times its original length, and, when completely finished, will have assumed the form of a strong wire $\frac{3}{8}$ to $\frac{1}{4}$ of an inch in diameter, and 40 to 50 feet in length.

A high temperature is an indispensable condition of success in rolling. The experience of the workman enables him to judge, from the appearance of the furnace, when the pile is at a welding heat, so that, when compressed in the rolls, the particles will unite. Sometimes it is necessary to give a fine polish or skin to the iron as it leaves the rolls; but this can only be done when the iron cools down to a dark-red colour, and by the practised eye of an intelligent workman.

Shearing.—The above operations would still be incomplete, unless the ironmaster had means of cutting the bars and plates to any required size and shape. The machinery for this purpose has of late been brought to a high degree of perfection, both in regard to power and precision.

The circular saw has been successfully applied for squaring and cutting the larger descriptions of bars, and

does its work, particularly in railway bars, with almost mathematical precision. This machine consists of a cast-iron frame or bed AA, fig. 35, bolted down to a solid

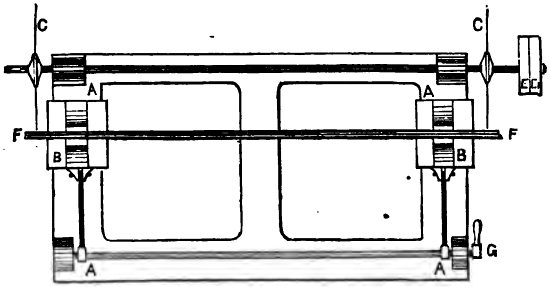
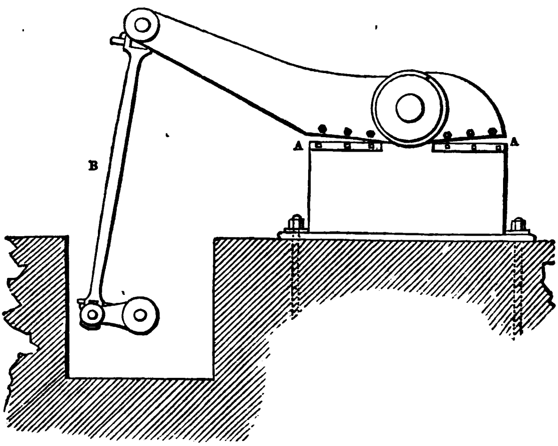


Fig. 35.

foundation, on the ends of which slide two frames, B B, to support the bar to be cut. The two circular saws or cutters, C C, are driven by straps passing over the pulleys D E, and rotate at the rate of 800 to 1000 revolutions per minute. The machine is set in motion by transferring the straps from the loose pulley D to the fast pulley E; and as soon as the required speed is attained, the frame B B is carried forward, and the bar F F along with it, by a lever G or eccentric motion, till the bar is cut through. The rate of cutting or pressure upon the saws may be regulated either by hand or weight; care must however be taken not to allow the saws to become too hot, and this is provided against by running them in a trough of water. By this process it is evident that the bar must always be cut square at the ends and correctly to the same length. We are informed that the circular saw for cutting railway bars is frequently driven by the Eolipile or Hero's engine, by which a speed of 2000 revolutions a

minute may be attained without the intervention of multiplying gearing.

A great variety of shears are used for cutting iron, some driven by cams or eccentrics, and some by connecting rods and a crank on the revolving shaft. In large iron-works it is necessary to have two or three kinds, some for cutting up scrap iron and bars for piling, and others for boiler-plates. Of the first we may notice two: one, shown in fig. 36, cuts on both sides at A A, and is driven



ig. 36.

by a crank and connecting-rod B. This machine is chiefly used for cutting puddled bars from the puddling-rolls, or any work required for shingling. The next machine, fig. 37, receives motion in the same manner, and also cuts on both sides, the cutters being fixed on the lever and moving with it. This is used for the same purpose as the last, and likewise for cutting scrap iron.

These machines are extensively used in the manufacture of iron; and before the introduction of the plate shears,

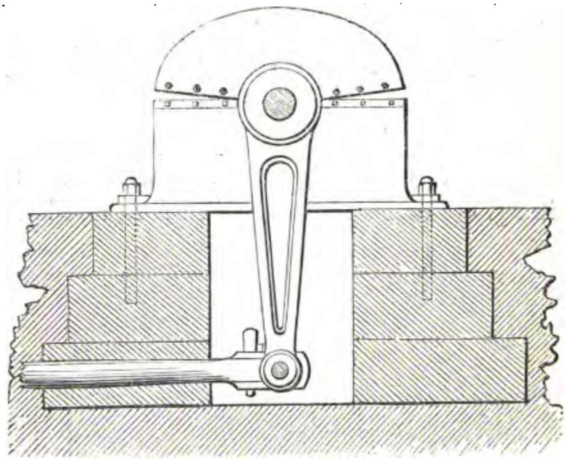


Fig. 37.

they were used, with some modifications, to cut boiler-plates, but the work was very imperfectly executed.

The demand for plates of large dimensions and greatly increased weight, such as those for the front and tube plates of locomotive and marine boilers, and those for tubular and plate bridges, created great difficulties, not only in piling, heating, and rolling, but also in cutting the plates accurately to the required size. To meet these demands, and more particularly for the manufacture of the large plates employed in the cellular top of the Britannia and Conway tubular bridges, Messrs G. B. Thorneycroft and Co. constructed a large shearing machine which cut upwards of 10 feet at one stroke. These shears have now come into general use, and are of great importance,

on account of the accuracy with which they cut plates of large dimensions square and even. Figs. 38 and 39 represent this machine; *a a a* is the standard and table on which the plate is fixed. This table slides forward at right angles to the shears or cutters AAA*A*. The top cutter descends by the action of three eccentrics *c c c*, which press upon the top of the frame B as it revolves, and force it down; and by one stroke, the knife AA cuts through the whole length of the plate, perfectly clean and straight. The plate is then reversed, the newly cut edge being held against the slopes, and the sliding frame again moved forward to the required width of the plate, when another stroke cuts the other side as before. The rapidity with which the plates are cut is another advantage of this machine, as great as the precision of its cut; and when the immense quantity of plates daily produced at Messrs Thorneycroft and Co.'s works are considered, its importance becomes evident.

At the Paris Universal Exhibition of last year (1855), a plate-cutting machine was exhibited, from the United States of America, which appears to effect the same operation as Messrs Thorneycroft and Co.'s. It consists of a strong cast-iron frame, nine or ten feet wide, having inserted along its face a steel plate, on which the iron to be cut rests, and is held firmly by a faller, which descends on the upper side of the plate. On the same side of the frame a revolving steel cutter, about nine inches in diameter, traverses the whole length of the frame, and in its passage cuts the plate, by compression, in a perfectly straight line, corresponding with the steel edge below. Cutting and shaving plates by a revolving disc has been

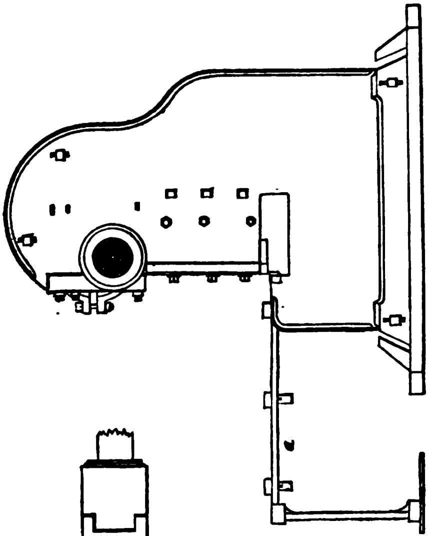


Fig. 39.—Side View.

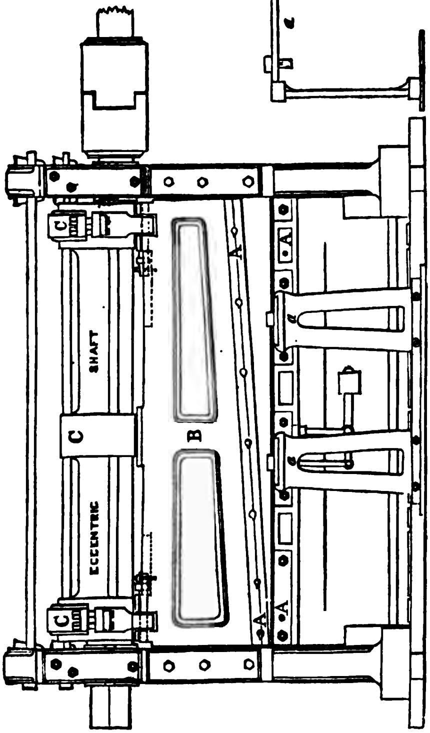


Fig. 38.—Elevation.

long in use, but the traversing motion in this machine is certainly new, and its application very creditable to the ingenuity of the inventor. The travelling cutter, which requires great power when cutting thick plates, is driven by a strap over a pulley at one end of the machine, and looking at the work it has to perform, and the complexity of its parts, we should consider it less effective and more liable to derangement than the simple and powerful machine of Messrs Thorneycroft.

General Summary. — Having

thus traced the processes for the conversion of crude into malleable iron, and the machinery employed, it only remains to give a general summary of the whole. As regards the arrangement of large iron-works, the general principle should be for the machinery to be classed and fixed in the order of the different processes, so that the products of one machine should pass at once to the next, and, in fact, the crude iron should be received at one end, and, having passed through all the processes, delivered at the other in the manufactured state.

The crude iron from the smelting furnace is either refined and puddled, or subjected to the boiling process, to get rid of the combined carbon, and render the iron malleable; it is then shingled by the forge-hammer, by the "Alligator," by Brown's squeezer, or by one of the other machines which have been invented for this purpose. It is then at once passed through the puddling rolls, where it is reduced to the form of a flat bar, and is then cut into convenient lengths by the shears. These pieces are again piled or faggotted together into convenient heaps, and re-heated in the furnace. As soon as a faggot thus prepared has been heated to the welding temperature, it is passed through the roughing-rolls to reduce it to the form of a bar, and then through the finishing-rolls, where the required form and size is given to it—either round or square bars, plates, &c. These are straightened and sheared to the required sizes, and are then ready for delivery. In most large works all these operations are carried on simultaneously with the smelting process, and in some with extensive mining operations for procuring the coal, ore, and limestone required to supply a production of several thousand tons of manufactured iron per month.

CHAPTER VII.

THE FORGE.

THE forging of iron has entered, of late years, so largely into the constructive arts, that the manufactures, however perfect in the rolling-mill, would be very imperfect indeed without the forge. To the discussion of this part of the subject there are many inducements, and we cannot but wonder at the many devices, and the numerous contrivances which present themselves for the attainment of the operations of the forge. In effecting these objects, Mr Nasmyth's steam-hammer is evidently the most effective, and to that instrument we are indebted for the welding of large masses of iron upon a scale previously unknown to the workers in that metal.

The old form of forge-hammer, or at least the form most suitable for heavy forgings, was that known as the belly-helve, and is shown in fig. 40. In this hammer the

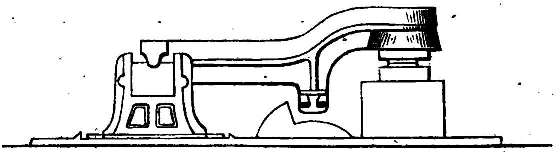


Fig. 40.

wheel carrying the cam by which it is lifted is placed

between the anvil and the fulcrum. The action is simple and the hammer is effective, but there is no provision for altering the intensity of the blow, whatever the nature of the work which had to be accomplished. For heavy forgings, scrap iron, cut up into small pieces by the shears, is usually employed. It is placed in a revolving hexagonal drum, by which the pieces knock each other about, and are cleaned from rust; and being piled or faggotted into convenient sized masses of one or two hundredweight, are placed in a reheating or piling furnace, similar to the reverberatory furnace employed in puddling. When they have reached a welding heat, they are placed under the helve, and united into a bloom or slab. These slabs form the masses of which larger forgings are built up. These, when too large to be handled by the forgeman, are supported by a crane beside the hammer, so that they can be turned over and manipulated with the greatest ease.

Mr Nasmyth took out his patent for the invention of a hammer, which has superseded all preceding forge tools in the better descriptions of work, in 1833; and from that time up to the present, it has maintained its ground against every innovation, and has performed an important duty in almost every well-regulated work in Europe. It consists of an inverted cylinder D, figs. 41 and 42, through which the piston-rod E passes, attached to the hammer-block F by means of bars and cross-key *k*, which press upon an elastic packing, to soften the blow of the hammer, which in heavy forgings and heavy blows operates severely upon the piston-rod The hammer-block FF is guided in its vertical descent by two planed guides

or projections, extending the length of the side-standards AA, between which the hammer-block slides. The attendant gives motion to the hammer by admitting steam from the boiler to act upon the under side of the piston, by moving the regulator I by the handle *d.* The length of stroke is regulated by increasing or diminishing the distance between the cam N and the valve lever O *o*, by turning the screws P and U by the bevil wheels *q q*. The lever O *o* operates by the cam N coming in contact with the roller *o*. As soon as this contact takes place, the further admission of steam is not only arrested, but its escape is at the same time effected, and the hammer, left unsupported, descends by its gravity upon the work on the anvil with an energy due to the height of the fall.

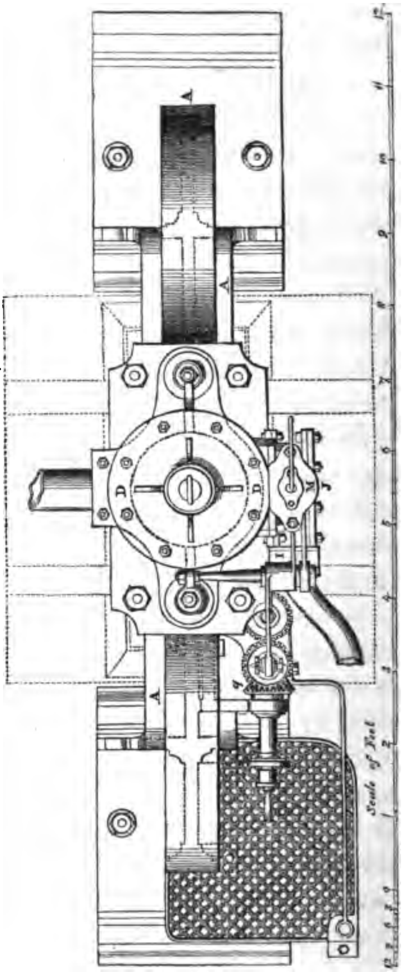


Fig. 42. Plan

From this description it will be seen that the movement of the roller *o* causes the shoulder of the rod P to get under the point of the trigger-catch *u*; the valve is by these means kept closed till the whole force of the blow is struck. The instant the operation is effected, the concussion of the hammer causes the latch X to knock off the point of the trigger from the shoulder on the valve-rod P, by means of the bent lever *s v*; and the instant this is accomplished, the valve is re-opened to admit the steam below the piston, by the pressure of steam on the upper side of the small piston in the cylinder M, forcing down the valve-rod, which in this respect is the active agent for opening the valve.

To arrest the motion of the hammer, it is only necessary to shut the steam-valve. During the process of forging, it is, however, desirable to give time between the blows, to enable the workman to turn and shift his work on the anvil; and to effect this reduced motion, the trigger U is held back from the shoulder of the valve-rod P by the handle *y*, which at the same instant opens the valve in the case J, and thus the action of the steam in the cylinder D retards the downward motion of the hammer. The result of these changes is an easy descent of the hammer, which vibrates up and down without touching the anvil, but ready for blows of any severity the instant the trigger is elevated above the shoulder of the valve-lever P. From this description it will appear evident that Mr Nasmyth's invention is one of the most important that has occurred in the art of forging iron. It has given an impetus to the manufacture, and affords facilities for the welding of large blocks of malleable iron that

could not be accomplished by the tilt and helve hammers formerly in use; and we have only to instance the forging of the sternposts and cutwaters of iron ships; the paddle-wheel and screw-shafts of our ocean steamers, some of them weighing upwards of 20 tons, to appreciate the value as well as the intensity of action of the steam-hammer.

Various modifications of Nasmyth's hammer are now in use. In Condie's, which has much merit, the piston-rod is stationary, and the cylinder moves carrying the block of metal forming the hammer on its bottom. The piston and piston-rod are suspended from the top of the framing, and the steam is admitted through the hollow piston-rod, and lifts the hammer by pressing against the top cylinder cover. In Morrison's, the piston-rod is made very large, so as to form the hammer, and slides through a gland in the fixed cylinder both at top and bottom. In some cases, as for anchor-forging, where the cast-iron standards are in the way, they are dispensed with, and the cylinder is supported on wrought-iron beams spanning the smithy, so as to leave a free space all round the anvil. Various changes in the valve gearing have been effected by Mr Naylor and others, and a lighter description of hammer has been introduced by Mr Rigby, in which the steam acts on both sides of the piston, urging it in its descent as well as lifting it after the blow is struck, by which means great rapidity of action is attained. In Mr Naylor's hammer, also, which has been made of large size, the advantage of admitting steam to both sides of the piston has been obtained, the downward stroke being increased in momentum, and the number of strokes in a

given time augmented. With small hammers acting on this principle, 250 blows per minute have been obtained.

In addition to the machinery of the forge, the V anvil, fig. 43, the natural offspring of the steam-hammer, came into existence from the same fertile source. It is chiefly employed for forging round bars and shafts, and may be thus described,—A being a section of the round bar or shaft to be forged, B the anvil-block, and C the hammer. From this it is obvious that, in place of the old plan, where the work is forged upon flat surfaces, as shown in fig. 44, and where the blows are diverging, the effect of the V anvil is a converging action, thus consolidating the mass, and enabling the forger to retain his work directly under the centre of the hammer. This is the more strikingly apparent, as the blows of the hammer upon a round shaft have the effect of causing the mass to assume the elliptical form, forcing out the sides as at AA at every successive blow; and this again, when turned, produces a spongy, porous centre, as shown in fig. 45. This process is, however, more clearly exemplified in Ryder's forging machines, where all the anvils are of the V form, for the forging of spindles, round bars, and bolts.

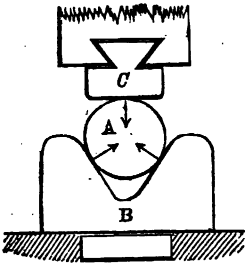


Fig. 43.

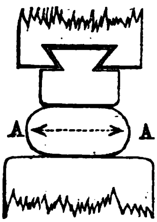


Fig. 44.

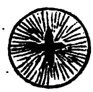


Fig. 45.

The most remarkable instance of a large forging, and one which will serve as an example of the best

methods of piling, &c., is the large wrought-iron gun, weighing before boring 25 tons. Mr Clay, under whose direction it was produced at the Mersey Works, Liverpool, gives the following account of the method of manufacture:—"It was built in seven distinct layers or slabs, and the forging occupied seven weeks; nor will this time seem unreasonable, when its dimensions and weight are considered. The first operation was to prepare a core of suitable dimensions, and nearly the whole length of the gun. This was done by taking a number of rolled bars, about 6 feet in length, welding them together, and drawing them out till the proper length was attained. A series of V-shaped bars were now packed round the core (fig. 46), the whole mass heated in a reverberatory furnace, and forged under the largest belly-helve hammer. Another series of bars were now packed on, and the mass was heated again and worked perfectly sound. Another longitudinal series of bars were still required over the whole length of the forging, which were

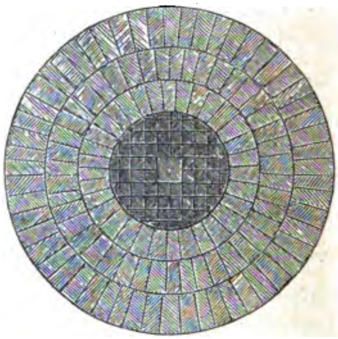


Fig. 46.

added, and the mass now presented a forging about 15 feet in length and 32 inches in diameter, but requiring to be augmented to 44 inches at the breech, tapering down to 27 inches at the muzzle. This was accomplished by two layers of iron placed in such a manner as to resemble hoops laid at right angles to the axis of the mass; and

after two more heatings, and careful welding, the forging of the gun was completed."

The next important addition to the implements of the forge is Mr Ryder's machine, patented some years since, for forging small articles, which, on account of the rapidity and precision of its operations, demands a notice in passing. It consists essentially of a series of small anvils about three inches square, supported from below by large screws passing through the frame of the machine. This screw was employed in order that the distance between the hammer and anvil might be accurately adjusted. Between the screw and the anvil, a stuffing of cork is introduced to deaden the effect of the blow. The hammers are arranged over the anvils, and slide up and down in the frame of the machine. The blow is effected by the revolution of an eccentric, acting by means of a cradle on the hammer-head,—the hammer, however, being lifted again by a strong spiral spring. The hammers make about 700 strokes a-minute. At the side of the machine is a cutter or shears worked by a long lever; with this the articles are cut to the required length as they are finished.

Figs. 47 and 48 represent this machine as improved by Messrs Platt Brothers of Oldham. AAAA are the anvils supported on a wedge B, instead of the screw, as in Ryder's. This substitution was made because the blows of the hammer tore off the threads of the screw, and the machine soon got out of order. The distance between the hammer and anvil is regulated by forcing forwards the wedge B by the rack and pinion C. The cork was then found insufficient as a stuffing, and an

immensely strong spring D was substituted. This spring

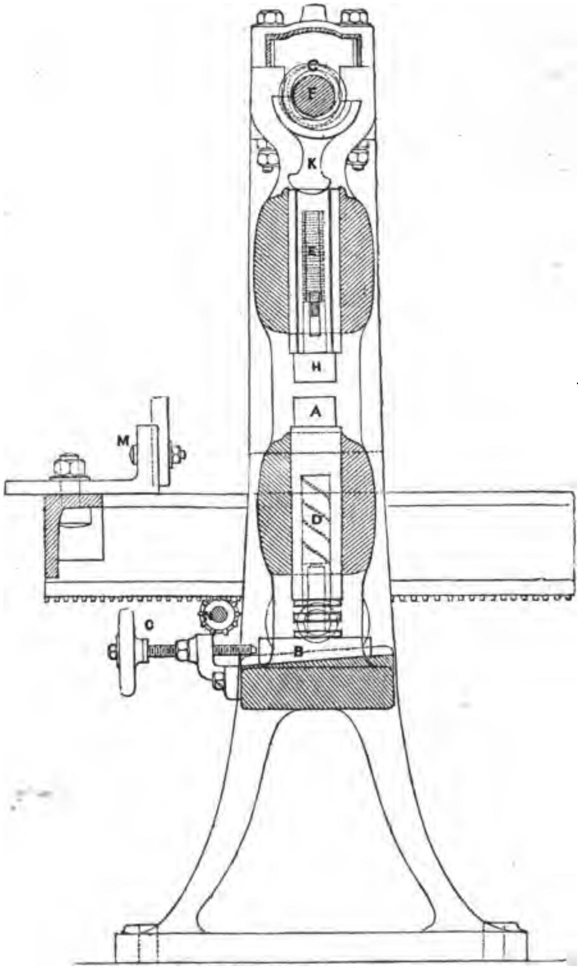
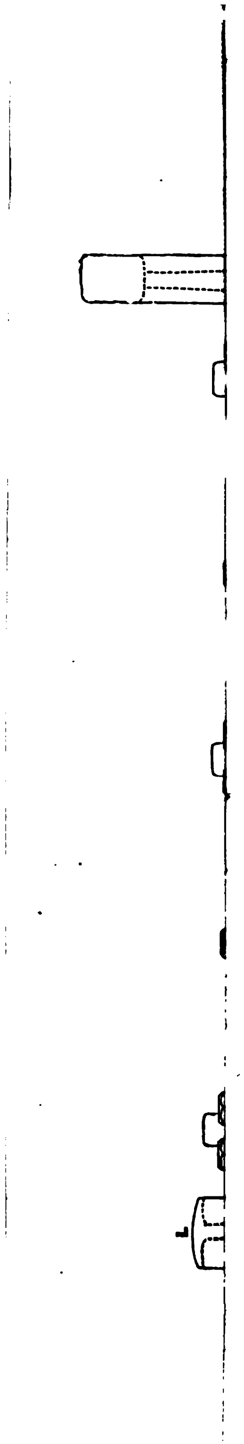


Fig. 48.—End Section.

is formed of a band of steel $1\frac{3}{4}$ inches broad, and $\frac{3}{8}$ thick,



coiled in a close spiral 2 inches in diameter, and 6½ long. It answers its purpose admirably. The hammers are shewn at HHHH, supported by springs, one of which is seen in the section at E. The eccentrics GGGG, driven by the shaft FF, in their revolution force down the cradles KKKK, which in their turn act on the tops of the hammers, the springs E keep the hammer-head always in contact with the cradles KK. The shaft FF is driven by a strap on the pulley LL. It is evident that, by the revolution of the shaft, the eccentric forces down the hammer, and then allows the spring to lift it again; the rapidity of the strokes is only limited by the power of the spring E to keep the hammer in contact with the cradle; if the eccentric revolves too fast, a violent jerking motion is produced. In Mr Ryder's machine, 700 strokes a-minute was the maximum; but Messrs Platt Brothers, by increasing the strength of the spring, run as high as 1100. A pair of knife edges, worked by the machine itself, has also been substituted for the hand-shears. These perform the work more rapidly and accurately than before, and leave the workman more at liberty. Dies are let into the surfaces of the hammers and anvils, which shape the iron as required.

The rapidity with which this machine executes all kinds of intricate work is truly remarkable; for instance, a bar about 2¾ × 2½ inches, will be reduced to 1¼ × 10 inches, and cut off in a minute. Set screws, bolts, spindles, and all kinds of small work, are produced at the same rate. Its precision is very effective; the articles are almost as true as if turned in a lathe, and very accurate as to size and weight. Other machines, called "lifts," have been,

and continue to be, used for forging a variety of forms and "*uses*;" but as these partake more or less of the principle employed in Ryder's machine, it will not be necessary to furnish further examples.

In conclusion, we may observe that the facilities afforded by the present age for the forging of malleable iron are without a parallel in the history of that material. Every known resource has been adopted, and every contrivance and device has been employed to meet the demands of a large and an intricate trade; and looking at the present resources of the country, and the admirable mechanical contrivances for the conversion of crude iron into the malleable state, it assuredly is not unreasonable to look forward to still greater improvements in the manipulations of the forge.

CHAPTER VIII.

MR BESSEMER'S PROCESS.

SINCE the above was written, an apparently new light has been thrown on the conversion of iron, by a paper read by Mr H. Bessemer at the last meeting of the British Association for the Advancement of Science, held at Cheltenham in August last (1856). In this paper the author announces to the world the discovery of an entirely new system of operations for the manufacture of malleable iron and steel. The crude metal is converted, by one simple process, directly as it comes from the blast furnace. We should detract from its clearness did we attempt to curtail the lucid description in which Mr Bessemer has recommended his invention to the manufacturers and the public; we therefore give the account in his own words:—

Mr Bessemer states that "for the last two years his attention has been almost exclusively directed to the manufacture of malleable iron and steel, in which, however, he had made but little progress until within the last eight or nine months. The constant pulling down and rebuilding of furnaces, and the toil of daily experiments with large charges of iron, had begun to exhaust his patience; but the numerous observations he had made

during this very unpromising period all tended to confirm an entirely new view of the subject, which at that time forced itself upon his attention—viz., that he could produce a much more intense heat, without any furnace or fuel, than could be obtained by either of the modifications he had used; and consequently, that he should not only avoid the injurious action of mineral fuel on the iron under operation, but that he would, at the same time, avoid also the expense of the fuel. Some preliminary trials were made on from 10 lbs. to 20 lbs. of iron; and although the process was fraught with considerable difficulty, it exhibited such unmistakeable signs of success, as to induce him at once to put up an apparatus capable of converting about 7 cwt. of crude pig iron into malleable iron in thirty minutes. With such masses of metal to operate on, the difficulties which beset the small laboratory experiments of 10 lbs. entirely disappeared. On this new field of inquiry, he set out with the assumption that crude iron contains about 5 per cent. of carbon; that carbon cannot exist at a white heat in the presence of oxygen without uniting therewith, and producing combustion; that such combustion would proceed with a rapidity dependent on the amount of surface of carbon exposed; and lastly, that the temperature which the metal would acquire would be also dependent on the rapidity with which the oxygen and carbon were made to combine, and consequently, that it was only necessary to bring the oxygen and carbon together in such a manner that a vast surface should be exposed to their mutual action, in order to produce a temperature hitherto unattainable in our largest furnaces. With a view of testing

practically this theory, he constructed a cylindrical vessel of three feet in diameter, and five feet in height, somewhat like an ordinary cupola furnace, the interior of which was lined with fire-bricks; and at about two inches from the bottom of it he inserted five tuyere pipes, the nozzles of which were formed of well-burnt fire-clay, the orifice of each tuyere being about three-eighths of an inch in diameter. They were put into the brick lining from the outside, so as to admit of their removal and renewal in a few minutes, when they were worn out. At one side of the vessel, about half-way up from the bottom, there was a hole made for running in the crude metal, and in the opposite side was a taphole, stopped with loam, by means of which the iron was run out at the end of the process. In practice, this converting vessel may be made of any convenient size, but he prefers that it should not hold less than one or more than five tons of fluid iron at each charge. The vessel should be placed so near to the blast furnace as to allow the iron to flow along a gutter into it; a small blast cylinder is required, capable of compressing air to about 8 lbs. or 10 lbs. per square inch. A communication having been made between it and the tuyeres before mentioned, the converting vessel will be in a condition to commence work; it will, however, on the occasion of its first being used, after relining with fire-bricks, be necessary to make a fire in the interior with a few baskets of coke, so as to dry the brickwork and heat up the vessel for the first operation, after which the fire is to be carefully raked out at the tapping hole, which is again to be made good with loam. The vessel will then be in readiness to commence work, and may

be so continued until the brick lining, in the course of time, is worn away, and a new lining is required. The tuyeres, as before stated, were situated nearly close to the bottom of the vessel; the fluid metal therefore rose some eighteen inches or two feet above them. It was therefore necessary, in order to prevent the metal from entering the tuyere holes, to turn on the blast before allowing the fluid crude iron to run into the vessel from the blast furnace. This having been done, and the fluid iron run in, a rapid boiling up of the metal was heard going on within the vessel, the iron being tossed violently about, and dashed from side to side, shaking the vessel by the force with which it moved. Flame, accompanied by a few bright sparks, immediately issued from the throat of the converting vessel. This state of things lasted for about fifteen or twenty minutes, during which time the oxygen in the atmospheric air combined with the carbon contained in the iron, producing carbonic acid gas, and at the same time evolving a powerful heat. Now, as this heat is generated in the interior of, and is diffused in innumerable fiery bubbles throughout the whole fluid mass, the vessel absorbs the greater part of it, and its temperature becomes immensely increased; and by the expiration of the fifteen or twenty minutes before named, that part of the carbon which appears mechanically mixed and diffused through the crude iron has been entirely consumed. The temperature, however, is so high, that the chemically combined carbon now begins to separate from the metal, as is at once indicated by an immense increase in the volume of flame rushing out of the throat of the vessel. The metal in the vessel now rises several

inches above its natural level, and a light frothy slag makes its appearance, and is thrown out in large foam-like masses. This violent eruption of cinder generally lasts about five or six minutes, when all further appearance of it ceases, a steady and powerful flame replacing the shower of sparks and cinders which always accompanies the boil. The rapid union of carbon and oxygen which thus takes place adds still further to the temperature of the metal, while the diminished quantity of carbon present allows a part of the oxygen to combine with the iron, which undergoes a combustion and is converted into an oxide. At the excessive temperature that the metal has now acquired, the oxide, as soon as formed, undergoes fusion, and forms a powerful solvent of those earthy bases that are associated with the iron. The violent ebullition which is going on mixes most intimately the scoriæ and metal, every part of which is thus brought into contact with the fluid oxide, which will thus wash and cleanse the metal most thoroughly from the silica and other earthy bases, which are combined with the crude iron; while the sulphur and other volatile matters, which cling so tenaciously to iron at ordinary temperatures, are driven off, the sulphur combining with the oxygen, and forming sulphurous acid gas. The loss in weight of crude iron during its conversion into an ingot of malleable iron, was found, on a mean of four experiments, to be 12½ per cent., to which will have to be added the loss of metal in the finishing-rolls. This will make the entire loss probably not less than 18 per cent. instead of about 28 per cent., which is the loss on the present system. A large portion of this metal is, however, recoverable by treating with

carbonaceous gases the rich oxides thrown out of the furnace during the boil. These slags are found to contain innumerable small grains of metallic iron, which are mechanically held in suspension in the slags, and may be easily recovered. It has already been stated that after the boil has taken place, a steady and powerful flame succeeds, which continues without any change for about ten minutes, when it rapidly falls off. As soon as this diminution of flame is apparent, the workman knows that the process is completed, and that the crude iron has been converted into pure malleable iron, which he will form into ingots of any suitable size and shape, by simply opening the tap-hole of the converting vessel, and allowing the fluid malleable iron to flow into the iron ingot-moulds placed there to receive it. The masses of iron thus formed will be perfectly free from any admixture of cinder oxide, or other extraneous matters, and will be far more pure, and in a forwarder state of manufacture, than a pile formed of ordinary puddle-bars. And thus, by a single process, requiring no manipulation or particular skill, and with only one workman, from three to five tons of crude iron pass into the condition of several piles of malleable iron, in from thirty to thirty-five minutes, with the expenditure of about one-third part the blast now used in a finery furnace with an equal charge of iron, and with the consumption of no other fuel than is contained in the crude iron. To those who are best acquainted with the nature of fluid iron, it may be a matter of surprise that a blast of cold air forced into melted crude iron is capable of raising its temperature to such a degree as to retain it in a perfect state of flu-

dity, after it has lost all its carbon, and is in the condition of malleable iron, which, in the highest heat of our forges, only becomes a pasty mass. But such is the excessive temperature that may be arrived at, with a properly shaped converting vessel, and a judicious distribution of the blast, that not only may the fluidity of the metal be retained, but so much surplus heat can be created as to remelt the crop ends, ingot runners, and other scrap, that is made throughout the process, and thus bring them, without labour or fuel, into ingots of a quality equal to the rest of the charge of new metal. For this purpose, a small arched chamber is formed immediately over the throat of the converting vessel, somewhat like the tunnel-head of the blast furnace. This chamber has two or more openings in the sides of it, and its floor is made to slope downwards to the throat. As soon as a charge of fluid malleable iron has been drawn off from the converting vessel, the workman will take the scrap intended to be worked into the next charge, and proceed to introduce the several pieces into the small chamber, piling them up round the opening of the throat. When this is done, he will run in his charge of crude metal, and again commence the process. By the time the boil commences, the bar ends or other scrap will have acquired a white heat, and by the time it is over, most of them will have melted and run down into the charge. Any pieces, however, that remain, may then be pushed in by the workman, and by the time the process is completed, they will all be melted and intimately combined with the rest of the charge; so that all scrap iron, whether cast or malleable, may thus be used up

without any loss or expense. As an example of the power that iron has of generating heat in this process, Mr Bessemer mentions that when trying how small a set of tuyeres could be used, the size he had chosen proved too small, and after blowing into the metal for one hour and three-quarters, he could not get up heat enough with them to bring on the boil. The experiment was therefore discontinued, during which time two-thirds of the metal solidified, and the rest was run off. A larger set of tuyere pipes were then put in, and a fresh charge of fluid iron run into the vessel, which had the effect of entirely remelting the former charge; and when the whole was tapped out it exhibited, as usual, that intense and dazzling brightness peculiar to the electric light.

"To persons conversant with the manufacture of iron, it will be at once apparent that the ingots of malleable metal which are produced by this process, will have no hard or steely parts, such as are found in puddled iron, requiring a great amount of rolling to blend them with the general mass, nor will such ingots require an excess of rolling to expel the cinder from the interior of the mass, since none can exist in the ingot, which is pure and perfectly homogeneous throughout, and hence requires only as much rolling as is necessary for the development of fibre; it therefore follows that instead of forming a merchant bar or rail by the union of a number of separate pieces welded together, it will be far more simple, and less expensive, to make several bars or rails from a single ingot; doubtless this would have been done long ago had not the whole process been limited by the size of the ball which the puddler could make.

"The facility which the new process affords, of making large masses, will enable the manufacturer to produce bars that, on the old mode of working, it was impossible to obtain; while, at the same time, it admits of the use of some powerful machinery, whereby a great deal of labour will be saved, and the process be greatly expedited. Mr Bessemer merely mentions this in passing, without entering into details, as the patents he has obtained for improvements in this branch of the manufacture are not yet specified. He next points out the perfectly homogeneous character of cast-steel—its freedom from sand cracks and flaws—and its greater cohesive force and elasticity, compared with the blister-steel from which it is made, qualities which it derives solely from its fusion and formation into ingots—all of which properties malleable iron acquires in like manner, by its fusion and formation into ingots in the new process. Nor must it be forgotten that no amount of rolling will give to blistered steel (although formed of rolled bars) the same homogeneous character that cast-steel acquires, by a mere extension of the ingot to some ten or twelve times its original length.

"One of the most important facts connected with the new system of manufacturing malleable iron is, that all the iron so produced will be of the quality known as charcoal-iron, not that any charcoal is used in its manufacture, but because the whole of the processes following the smelting of it are conducted entirely without contact with, or the use of any mineral fuel; the iron resulting therefrom will, in consequence, be perfectly free from those injurious properties which that description of fuel

never fails to impart to iron that is brought under its influence. At the same time, this system of manufacturing malleable iron offers extraordinary facility for making large shafts, cranks, and other heavy masses; it will be obvious that any weight of metal that can be founded in ordinary cast-iron, by the means at present at our disposal, may also be founded in molten malleable iron, and be wrought into the forms and shapes required, provided that we increase the size and power of our machinery to the extent necessary to deal with such large masses of metal. A few minutes' reflection will show the great anomaly presented by the scale on which the processes of iron-making are at present carried on. The little furnaces originally used for smelting ore have, from time to time, increased in size, until they have assumed colossal proportions, and are made to operate on 200 or 300 tons of material at a time, giving out 10 tons of fluid metal at a single run. The manufacturer has thus gone on increasing the size of his smelting furnaces, adapting to their use the blast-apparatus of the requisite proportions, and has by this means lessened the cost of production, in every way ensuring a cheapness and uniformity of production that could never have been secured by a multiplicity of small furnaces. While the manufacturer has shown himself fully alive to these advantages, he has still been under the necessity of leaving the succeeding operations to be carried out on a scale wholly at variance with the principles he has found so advantageous in the smelting department. It is true that, hitherto, no better method was known than the puddling process, in which from 4 cwt. to 5 cwt. of iron is all that can be operated

upon at a time, and even this small quantity is divided into homeopathic doses of some 70 lbs. or 80 lbs., each of which is moulded and fashioned by human labour, carefully watched and tended in the furnace, and removed therefrom, one at a time, to be carefully manipulated and squeezed into form. Considering the vast extent of the manufacture, and the gigantic scale on which the early stages of its progress are conducted, it is astonishing that no effort should have been made to raise the after processes somewhat nearer to a level commensurate with the preceding ones, and thus rescue the trade from the trammels which have so long surrounded it. Mr Bessemer then adverts to another important feature of the new process, the production of what he calls semi-steel. At the stage of the process immediately following the boil, the whole of the crude iron has passed into the condition of cast-steel of ordinary quality. By the continuation of the process the steel so produced gradually loses its small remaining portion of carbon, and passes successively from hard to soft steel, and from softened steel to steely iron, and eventually to very soft iron; hence, at a certain period of the process, any quality may be obtained: there is one in particular, which, by way of distinction, he calls semi-steel, being in hardness about midway between ordinary cast-steel and soft malleable iron. This metal possesses the advantage of much greater tensile strength than soft iron; it is also more elastic, and does not readily take a permanent set, while it is much harder, and is not worn or indented so easily as soft iron. At the same time it is not so brittle or hard to work as ordinary cast-steel. These qualities render it eminently well adapted to purposes where

lightness and strength are specially required, or where their is much wear, as in the case of railway bars, which, from their softness and lamellar texture, soon become destroyed. The cost of semi-steel will be a fraction less than iron, because the loss of metal that takes place by oxidation in the converting vessel is about 2½ per cent. less than it is with iron; but as it is a little more difficult to roll, its cost per ton may fairly be considered to be the same as iron. As its tensile strength is some 30 or 40 per cent. greater than bar iron, it follows that for most purposes a much less weight of metal may be used, so that taken in that way the semi-steel will form a much cheaper metal than any we are at present acquainted with.

"In conclusion, Mr Bessemer observes that the facts he has discovered have not been elicited by mere laboratory experiments, but have been the result of operations on a scale nearly twice as great as is pursued in the largest iron-works, the experimental apparatus converting 7 cwt. in thirty minutes, while the ordinary puddling furnace makes only 4½ cwt. in two hours, which is made into six separate balls; while the ingots or blooms are smooth, even prisms ten inches square by thirty inches in length, weighing about as much as ten ordinary puddle balls."

Mr Bessemer's first patent, in reference to this process, was taken out in 1855, and claimed improvements in the manufacture of cast-steel, consisting of the forcing of currents of air or of steam into and amongst the molten crude iron, or of remelted pig or refined iron, until the metal so treated is rendered malleable and has acquired

other properties common to cast steel. A second patent in the same year claimed the application of the same process to refining iron previous to puddling, or by preference the conversion of the crude iron by a single process, and casting it into ingots suitable for rolling into bar iron or plates. In February 1856, further details of the process are described in a patent, the object of which is stated to be the conversion of molten crude iron or remelted pig or finery iron into steel, or malleable iron without the use of fuel for reheating or continuing to heat the crude molten metal, such conversion being effected by forcing into and among the molten mass currents of air or gases capable of evolving sufficient oxygen to keep up the combustion of the carbon contained in the iron till the conversion is accomplished. In March, May, August, and November 1856, and January 1857, further details of methods of introducing the air, assisting the combustion by the use of carbonaceous matter and oxides, and forming ingots, or rolling the molten metal direct, were patented.

Since that time Mr Bessemer has pursued unremittingly the perfecting of his process, and the results at which he has arrived he communicated in May 1859 to the Institute of Civil Engineers. The primary source of difficulty to be overcome was the removal of the sulphur and phosphorus, abundantly present in ordinary cast iron, and which the high temperature and copious supply of air in the Bessemer process did not seem to affect. Steam, hydrogen, and silicates of iron and manganese were tried, and with partial success. But the employment of crude iron, free from these noxious elements, appeared the most certain escape from the difficulty, and with Indian and Nova

Scotian iron the process became successful. Cast-steel works were erected at Sheffield, and in these the system has since been in operation.

For the production of malleable iron, however, this fine description of cast metal was, from its cost, inapplicable, and the iron smelted from specular, hæmatite, and spathose ores, was looked to, to supply the requisite material. Iron was obtained from Cleator, Weardale, and the Forest of Dean, fit for the purpose, and with the converting vessel, shown in the annexed cut, malleable iron has been produced. Mr Bessemer thus describes the method of operation: "The vessel is mounted on axes near its centre of gravity. It is constructed of boiler plates, and lined with fire-brick, road-drift, or 'ganister,' which resists the heat better than any other material yet tried, and has also the advantage of cheapness. The vessel having been heated, is brought into a horizontal position, so that it may receive its charge of molten metal without either of the tuyeres being beneath the surface. No action can therefore take place until the vessel is made to assume the vertical position (fig. 49). The process is thus in an instant brought into full activity, and small, though powerful, jets of air spring upward through the fluid mass. The air, expanding in volume, divides itself into globules, or bursts violently upwards, carrying with it some hundred weight of fluid metal, which again falls into the boiling mass below. Every part of the apparatus trembles under the violent agitation thus produced. A roaring flame rushes from the mouth of the vessel; and, as the process advances, it changes its violet colour to orange; and finally to a voluminous pure white flame.

tract from Mr Bessemer's papers from the fact that his process of decarbonisation and boiling, although not exercised to the extent of becoming general, is nevertheless attended with results highly satisfactory as regards the purity and homogeneous state of the metal produced. The greatly increased temperature, rapid combustion, and violent ebullition, and the changes of colour from violet to orange and thence to white, are indications of the different stages of the process, which enable the operator to judge with great certainty when it is time to stop, either in the production of steel of different qualities or malleable iron.

Now, in the usual process of puddling in the reverberatory furnace, these indications are not present to the same extent, as the puddler, when producing either iron or steel, has not only to judge from the colour and the tenacious state of the mass as he gathers it into the balls, but he must close his damper at the exact moment of time, in order to produce the quality of metal, whether steel or iron, that he may require. This is the most difficult part of the process, as the workman has not only to watch his furnace intensely, but the laborious operation of stirring and balling the molten mass is so great as to render him unfit for the double duty of violent muscular action and the exercising of a sound judgment in the appearance of the furnace. To the toil and labour of this exhausting process we may therefore trace the great uncertainty as respects the quality of the so-called homogeneous mass, which is sometimes steel, sometimes iron, or between the two, as it pleases the puddler and his assistant.

Now, the Bessemer process, if it can be safely and profitably carried out, will in a great measure remedy these defects, and give greatly increased confidence in the uniformity, strength, and other properties of the metal produced.

For the production of large plates, Mr Bessemer has tried one especially interesting experiment, and that is to produce them direct from the fluid metal, without any preliminary solidification. He has rolled a plate of considerable dimensions by pouring the fluid metal into the space between two rolls cooled by water, the metal chilling in a plate as the rolls revolve. If this method could be carried out successfully, we might hope for much larger and more homogeneous plates than is possible with the present system of puddle balls. We might in fact calculate on a continuous web of iron from the rolls, on the same principle as that produced by the paper-machine, provided the converting or leading furnaces are sufficiently large and numerous to keep up the supply.

The results of experiments on the tensile strength of the iron and steel produced by this process will be found in Chapter X. They show a very high tenacity.

Wrought iron, as ordinarily made, is found to possess about one-half of the power of cohesion which it has when manufactured in a fluid state, and is allowed to retain a minute quantity of carbon; indeed, iron, under the various forms in which it is met with in commerce, presents an anomaly not to be found in any other of the staple manufactures of this country.

When in the state of cast-iron, the metal contains 4 per cent. of carbon, has a tensile strength of 18,000 lbs.

per square inch, and is worth L.3 per ton. Deprive it of this 4 per cent. of carbon, and it becomes malleable iron: it has then a tensile strength of 56,000 lbs. per square inch, and is raised in value from L.3 to L.8 per ton. But if we leave in it 1 per cent. of the carbon it originally contained, it will have a tensile strength of at least 130,000 lbs., and its selling price will have risen from L.8 to L.50 per ton. Such facts may well suggest the question, Cannot iron be purified, and this 1 per cent. of carbon be left in it, without raising its cost to L.50 per ton?—Cannot we have the great cohesive strength, the hardness and the homogeneous character of iron fully developed, without that commercial barrier which the old system of making cast-steel has ever placed in the way of its employment for all constructive purposes?

Until very recently, cast-steel has been considered to be a hard and brittle material, and has been employed almost exclusively for cutting tools—its hardness, and the difficulty of working it, rendering it unfit to take the place of iron for general purposes. Well carbonised cast-steel, made by the Bessemer process, has been found to bear a tensile strain of 160,000 lbs. per square inch; while pure decarbonised iron, made by the same process, will only bear on an average 72,000 lbs.

Within these limits, however, there is an ample margin for the manufacture of several distinct qualities of malleable metal, each especially suited to peculiar uses. Thus, steel containing 1¼ per cent. of carbon, and capable of bearing a tensile strain of 150,000 lbs., may be employed for the upper web of a plate or box girder to great advantage, where it would bear safely an enormous compressive

force, but it would be a very improper material to employ in the construction of a steam-boiler.

The light cast-steel girders, of 70 feet span, erected last year on the Thames by the Corporation of the City of London, were made of a mild, tough steel, bearing only a tensile strain of 45 tons per square inch, and are of half the scantling of the wrought-iron girders used in the same structure. In many cases it will, however, be perfectly safe to employ a somewhat harder metal than these girders were made of. For instance, some large pump-rods recently made, in lengths of 30 feet each, were required to stand a proof of 120,000 lbs. per square inch. It has, however, been found that iron containing from $\frac{1}{4}$ to $\frac{1}{2}$ per cent. of carbon, and capable of bearing from 90,000 to 100,000 lbs. per square inch, is most suitable for general purposes, but it is especially so for steam boilers, as it will bear punching and flanging like a sheet of copper.* The engraving fig. 50, carefully traced from a photograph by Mr Charles Wright, shows several pieces of the Bessemer steel, of the tough quality last named, all of which have been bent or twisted cold. Among them are two pieces of a cast-steel rail, one formed into a spiral, which partly untwisted itself when released from the machine, and the other folded up by several blows from a $2\frac{1}{2}$ ton steam-hammer. There is also shown a 3-inch square steel bar, which affords a good example of the power of this metal to resist fracture by a torsional strain.

* In one establishment near Manchester, six of these steel boilers are in use, under a constant working pressure of 100 lbs. per square inch. Their dimensions are 30 feet in length by 6 feet 6 inches in diameter, the plates being $\frac{5}{16}$ of an inch in thickness.

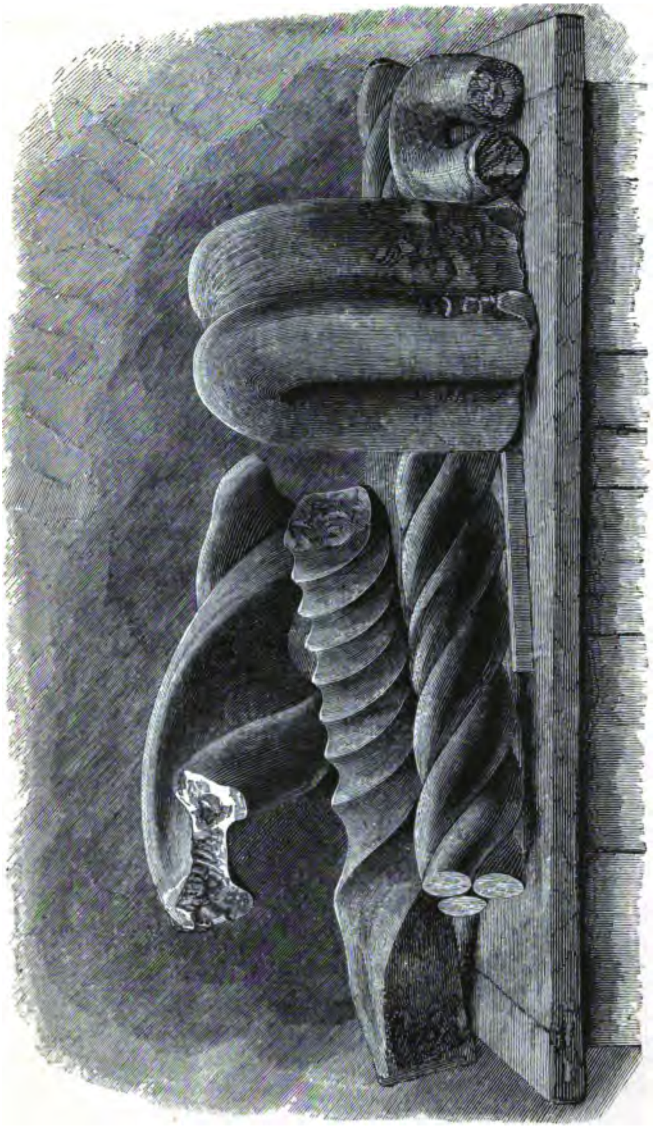


Fig. 50.

Its angles, originally 3 inches asunder, are seen to approach within 1⅛ of each other, the original flat sides of the bar being formed into a deeply indented groove; and in the space of 12 inches from the fractured end, the angles, measured on their present extended line, are equal to 22 inches in length. These examples of extreme toughness and power to resist fracture until entirely altered in form, will, it is hoped, tend to dispel the very popular error, that cast-steel "snaps like glass," and cannot be safely employed as a substitute for wrought iron.

To the details of the process by which these results have been obtained, at a cost which can compete successfully with common iron, already given, Mr Bessemer has furnished the following additional particulars. Fig. 51 represents an external view of the converting vessel A and its accessories. The converting vessel has already been described and figured at page 145. This vessel is supported on axes, which project on each side of it, a little above its centre of gravity, and these rest on the standards B, which are firmly secured to the foundation. On one of the axes a spur wheel, C, is fixed, which receives motion from the pinion and handle D, so that at any time a semi-rotatory motion of the vessel may be effected by simply turning this handle in the required direction. In front of the vessel is fixed a hydraulic crane E, having an arm G, to which the casting-ladle H is attached. A semicircular casting-pit J is sunk in the floor, and has placed in it any convenient number of ingot-moulds K, arranged side by side, all of them being equidistant from the centre of the crane. The casting-ladle is raised and lowered down as near as convenient to

of filling the moulds is rendered necessary, on account of the extreme difficulty which is found in pouring the fluid steel over a lip formed on the top edge of the ladle, without allowing some of the fluid slag to go over with the metal and become intermixed with it. The rapidity with which the solidification of malleable iron takes place in a cold metal mould would prevent any slag that might be taken down with the falling stream from rising again to the surface. It is also essential that the metal should descend in a vertical stream down the centre of the mould; for if the stream is allowed to flow in contact with the cast-iron mould, the latter is immediately melted at that part. and becomes firmly united to the ingot.

The blast of air is conveyed into the converting vessel through one of the trunnions, which is made hollow for that purpose, and passes by a pipe into the tuyere-box R, which is so arranged as to be easily detached. Two or more of these tuyere-boxes are provided, so that on the removal of one set of tuyeres, another box and tuyeres may be in readiness to replace it. The tuyeres are seven in number, each one having five separate holes through it, of $\frac{1}{4}$ of an inch in diameter. These holes allow the air to pass vertically upwards into the mass of fluid metal in 35 separate jets.

When the apparatus cannot be supplied with fluid metal direct from the blast-furnace, it has been found preferable to melt the pig-iron in a reverberatory furnace, from which the metal may be conveyed in a ladle to the converting vessel, which is moved into a nearly horizontal position to receive it, the tuyere end of the vessel being sufficiently raised to keep the orifices of the tuyeres above

the level of the metal. When about 25 cwt. of crude iron has been run in, the blast is turned on, and the vessel is rapidly moved into the position shown in fig. 49, when the process instantly commences, the jets of air rushing upwards, expanding in volume, and dividing into an infinite number of globules, which become dispersed throughout the fluid mass. The silicium is first attacked, neither the iron nor carbon being operated upon to any extent while any silicium remains. When the crude iron contains about 1¼ per cent. of silicium, it requires about twelve minutes' blowing to remove it, during which time only a few sparks make their appearance; but as soon as the silicium is nearly all eliminated, the carbon and iron are more and more acted upon. At about this period, two minutes suffice to entirely change the outward indications of the process, for in that short space of time the bright sparks previously seen issuing from the vessel have almost wholly disappeared, and a voluminous flame rushes out of the mouth of the vessel, gradually passing from orange to a brilliant white. The light is so intense as to project shadows of every object on the wall of the building, even at mid-day. In about 25 minutes from the commencement of the process, this flame is observed to drop off suddenly, thus indicating the complete decarbonisation of the metal. Combustion can therefore no longer go on. The vessel is then immediately turned again into the horizontal position, and a small quantity of carburet of manganese, mixed with carburet of iron and silicium, is added, the vessel is again turned up, and the blast is driven through it as before; the manganese almost wholly disappears in a few seconds, but the carbon is retained. The steel may

thus be carbonised to any desired extent, entirely depending on the known quantity of carbon thus added to the converted metal, while the carburet of manganese effects precisely the same chemical change as it does in the thousand other steel pots in which it is daily employed in Sheffield—*i. e.*, it confers on it the property of welding and working more soundly under the hammer. Mr Heath first discovered this important fact while residing in India, and in the year 1839 he patented the discovery in England. So well did he understand the chemical changes brought about by the employment of this alloy in steel, without reference to the mode by which the steel was manufactured, that he claimed in his patent "the employment of carburet of manganese in any process whereby iron is converted into cast-steel." No sooner is the mixture of the metals effected than the casting-ladle is brought under the mouth of the vessel, which is then turned down, as shown in fig. 51, and the fluid steel poured into the ladle; the ram is then raised by simply turning a handle, and the crane-arm is swung round so as to bring the orifice of the ladle over one of the moulds; the handle N is then depressed, which raises the fireclay valve, and allows the fluid steel to flow in a clear round stream into the iron moulds beneath; all slags or dry oxides float on the surface of the fluid in the ladle, and cannot possibly enter the mould. When one mould is filled, the cone-valve is shut down and the ladle is moved over the next mould, and so on until all the steel is formed into ingots, the process occupying 30 minutes from the pouring in of the crude iron to the formation of the metal into cast-steel blooms or ingots.

The metal silicium plays a most important part in this process; and however injurious it may be found when present in comparatively large quantities, it is of the utmost service when employed in minute doses. Whenever decarbonised fluid iron is deprived of every atom of silicium, as in the process just described, or when blister-steel free of silicium is melted in crucibles, it is found to disengage gas rapidly in the act of cooling (in the same way that silver does), and thereby produces unsound castings, the steel in some cases boiling in the cold cast-iron mould so furiously as to run over the top, and more than half empty the mould. When the metal is in this unmanageable state, it has been found that 1 lb. of silicium put into 2000 lbs. of steel entirely stops the boiling action, and causes the metal to lie as quietly in the mould as common cast-iron would do. Now, the metal silicium is most difficult to obtain in such quantities as are required for commercial purposes, but, like manganese, may be reduced most readily when intimately combined with oxide of iron. Hence the metal put in at the end of the process is an alloy of manganese, silicium, and iron, obtained by the simultaneous reduction of their oxides previously mixed in the requisite proportions.

It is curious how, by the merest accident, and entirely without their knowledge of the fact, the steelmakers on the old plan have for the last forty or fifty years taken the benefit of this alloy. In making the 5000 crucibles which daily are put into the steel furnaces of Sheffield, it has been found most convenient to form them with a small round hole in the bottom. These crucibles are placed in the furnace upon a flat lump of fireclay, and a handful

of sand is thrown into them for the purpose of stopping up this hole and preventing the escape of the steel. The intense heat of the smelting process, aided by the carbon present in the steel, and by the small quantity of charcoal usually put into the crucible with it, suffices to reduce a small portion of the sand or silicic-acid into the metallic state; the silicium thus formed alloying the steel, gives that quietness and freedom from boiling known in the trade as "dead melted." The analysis of cast-steel of the highest qualities invariably shows this alloy of silicium.

At present there are two distinct modes of working the Bessemer process: that just described is the system preferred in England; but in India and Sweden, where the process is rapidly extending, the fixed vessel has been adhered to, and the various qualities of steel and malleable iron at the works of Mr Göranson of Geffle are entirely regulated by the quantity of blast and the time of blowing; no manganese is used at any stage of the process, nor is any metal added to regulate the temper of the steel. Over 700 tons of steel so produced have found their way into the English market within the last seven months, the whole of which was made in precisely the manner described by Mr Bessemer in his paper read at Cheltenham in 1856, and quoted at the commencement of this chapter.

In the conversion of crude iron into steel by a blast of air, a great waste of metal may be made, if the quantity and mode of applying the blast is not directed by a person having a practical knowledge of the process; but with this knowledge (easily acquired), the loss of metal is extremely small. Mr Göranson, who employs the fluid crude iron

direct from the blast furnace, took the trouble to weigh accurately all the fluid iron employed for this purpose at his works during a whole week, and in his report of the results obtained, he states the actual loss in weight to be 8·72 per cent.—that is, the cast ingots, together with the scrap or steel accidentally spilled, was within 8·72 per cent. of the weight of cast-iron tapped from the blast furnace. At the Sheffield works the iron is melted in a reverberatory furnace, which causes a loss of 5 or 6 per cent. in the first instance; and coke-made pig-iron being less pure than that employed by Mr Göranson, a further loss of about 10 per cent. takes place in the converting vessel, making a total loss of 15 or 16 per cent. of the pig-iron employed. The loss has occasionally been as low as 13 per cent. and as high as 20, but it is believed that it will be further reduced when converting five tons of crude metal at a single charge. Not only is the loss in the converting process small; but in the after process of hammering and rolling, the loss from oxidation is much less than that which takes place in making wrought-iron in the usual way—*firstly*, because the temperature of the blooms is much less; *secondly*, because it is only worked once without piling; and, *thirdly*, because the solid ingot presents very much less surface to oxidation than a pile of small bars. Hence it follows that a ton of pig-iron may be converted by the new process into bars or plates of cast-steel in much less time, with less fuel, with less manual labour, with less engine power, and with a less loss of metal, than the same ton of pig-iron can be made into common wrought-iron by the ordinary process, to say nothing of the increased commercial value of the product.

An important feature of the new process is, that it affords great facility for the production of large masses of tough malleable metal, without increasing the cost in the same ratio as in the old process, where every large mass is built up of small pieces more or less perfectly united, and more or less injured in quality, by being reduced to a soft state approaching fusion, in order to favour the adhesion of each successive piece as it is added to the mass.

When a large forging of the Bessemer steel is required, the fluid metal is poured into a massive iron ingot mould equal in weight to the fluid metal, where it passes in a few minutes into a solid state. The rapidity with which the iron-mould absorbs the heat is shown in eight or ten minutes after pouring in the fluid steel, by the mould becoming red-hot, although sometimes weighing more than a ton. The result of this rapid solidification is the formation of small crystals not easily detached from each other, as is the case with large and well defined crystals produced by slow solidification.

In all cases the employment of metal containing phosphorus should be avoided, as that substance assists in the development of crystals in a most extraordinary manner, and thereby causes the metal to be cold-short. The effect of this substance on some other metals is most remarkable: if one ounce of phosphorus be put into one cwt. of melted tin, it entirely alters the whole character and properties of the metal; for on cooling, the mass crystallises in large and distinct crystals, having so feeble a cohesion as to allow of their separation by a very light blow. Fig. 53 is copied from one of Mr Wright's photographs of a fragment of phosphorised tin, and shows how large and

perfectly the crystals are developed in a piece of only 2 lbs. in weight.

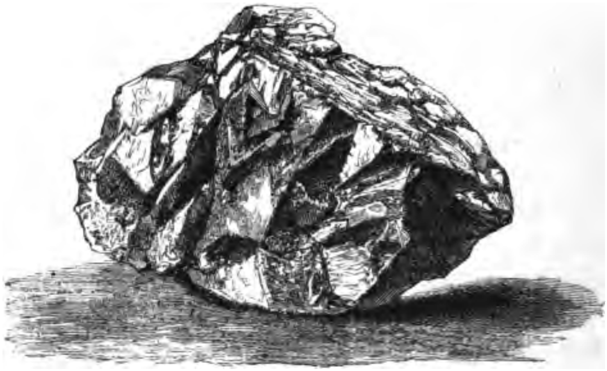


Fig. 53.

As an illustration of the mode of treating large masses, an instance may be given in which the crude pig-iron was tapped from the reverberatory furnace at 10 A.M., and by 10.30 was converted into mild cast-steel, and formed into an ingot of 16 inches square by 3 feet 6 inches long; at 10.50 it was removed from the mould and put into the heating furnace, in order to restore a little of the heat taken from its exterior by the mould, and thus render the whole mass nearly uniform in temperature, the central part still being a little higher in temperature, so as to be readily acted upon by the hammer. During the afternoon this ingot was formed by hammering into a truncated cone 7 feet 10 inches long, and 10 inches diameter at one end, and 8 inches at the other, and was the first gun-block made by the Bessemer process in steel. In December last it was finished at Liege, and proved

under the direction of the Belgian Minister of War; it was bored for a 12-lb. shot, the interior being $4\frac{23}{32}$ inches diameter, the exterior being finished at $9\frac{1}{2}$ inches diameter at the breech end, and $7\frac{1}{2}$ inches at the muzzle, weighing 9 cwt. and 23 lbs.; whereas an ordinary cast-iron gun of the same calibre would measure 16·22 inches diameter at the breech, and 10·39 at the muzzle, weighing 34 cwt. The steel gun (if such a thin tube may so be called) was ordered to be proved *à l'outrance*, with increasing charges of powder and shots until it should give way. The charge for commencing the proof was 4 lbs. $7\frac{3}{4}$ oz. of powder and two 12-lb. shots. The charges of powder and the number of shots were increased up to the twenty-second round, when the gun gave way under a charge of 6 lbs. $11\frac{1}{2}$ oz. of powder and eight 12-lb. shots. The gun did not burst longitudinally, but separated in two pieces, about four feet of the muzzle end being blown off. This will afford some idea of the great tenacity of this metal, even when of large section, and not much worked under the hammer. Nor must this be considered as a maximum result; since the precise quality of metal best suited to this purpose can only be determined by numerous trials, it is highly improbable that the best temper was arrived at on the first attempt.

While cast-steel made by the direct conversion of pig-iron is quietly working its way into the great engineering establishments of this country, and some of our most wealthy and enterprising iron and steel manufacturers are preparing to exchange the old for the new system of making steel, the daily working of the process only affords fresh proof of the desirability of a still further improve-

ment in the apparatus employed. The change of tuyeres in the present vessel causes a delay of four or five hours, and allows the vessel to get cold in the interval, and thus impedes that rapid and continuous working which is so highly desirable. The loss of time occasioned by the present mode of setting the tuyeres has led to an important improvement in the construction of the apparatus, which will enable the workmen to convert a charge of metal every hour, night and day without interruption, and thus render the heating of the vessel from time to time with fuel quite unnecessary, and enabling a small vessel to turn out 200 tons of steel per week.

In this improved converting vessel the globular form has been chosen, because it is easy of construction, and well suited to sustain its great weight from two points of support; the lining of the interior is also more stable than with any other form, and presents less surface for radiation of heat. The apparatus is shown in section in fig. 54, and in elevation in fig. 55. The casting pit extends beneath the vessel A, which is placed so low down that a charge of crude iron may be run into it by a gutter on the level of the floor; like the former vessel it is supported on trunnions, and carries on one of them a pulley-wheel B, around which passes a wire-rope attached to a hydraulic lift or ram; a counterweight is suspended from the opposite side of the drum. The whole of this apparatus being below ground is operated upon in a similar manner to the casting crane before described, and which is also used with the new vessel.

In this modification of the apparatus the tuyere box is entirely dispensed with, the air not being admitted through

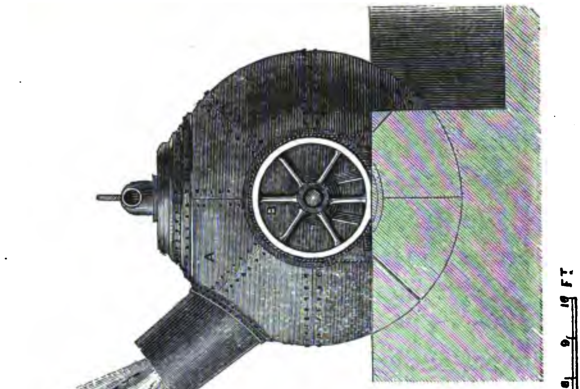


Fig. 55.

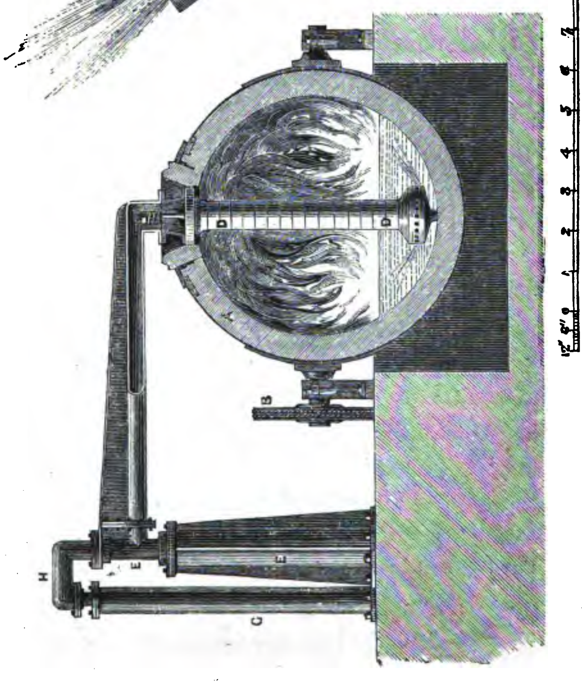


Fig. 54.

separate tuyeres let into the bottom of the vessel, but the blast is brought downwards by a single tuyere, D, from the upper part of the vessel, so that the tuyere may be removed from the vessel and a new one put into its place without disturbing the lining of the vessel. It is raised or lowered when required by a small hydraulic crane E, having a long tubular arm extending to the upper end of the tuyere. The blast-pipe G rises vertically up from the floor level, and is parallel with the plunger of the hydraulic crane; an elbow-pipe H, having a telescopic joint, establishes a communication at all times between the blast-pipe and the tuyere, notwithstanding the motion of the crane, in any direction; thus the whole movements of the converting and casting apparatus are effected steadily, and without effort, by any workman in charge of the handles of the hydraulic apparatus. After a charge of metal has been converted, the tuyere is lifted out, and the vessel turned round so as to pour it into the casting ladle; the vessel is then turned up, and the tuyere again inserted, or a new one is put in if the old one is too much worn. The tuyere is composed of circular bricks having a central hole, through which a stout iron rod passes, and by means of which the tuyere is firmly held together; the passages for the air surround the central rod, and the current of air passing down them, prevents the rod from being made too hot. The vessel is 7 feet in external diameter, and capable of converting from 2 to 2½ tons of steel at each charge, the process occupying about 25 minutes.

In order to prevent a stoppage of the operations in the converting-house by any accident occurring to the con-

verting apparatus, it will be found preferable to mount two vessels at each casting-pit. This plan has also the advantage of allowing the two vessels to be used simultaneously when any very large ingot or casting is required; and it must be borne in mind that this facility of producing steel or malleable iron castings in loam moulds is another most important feature of the new process, arising out of the treatment of malleable iron in a fluid state. Wherever lightness and great strength are required in iron castings, this material should not be overlooked by the engineer. The framing of marine engines, screw propellers, the cylinders of hydraulic presses, and a hundred other uses, will present themselves, when it is known that castings can be made of this malleable metal, and portions of these castings may be forged and drawn out if required, and will give to such parts a great additional strength. For example, the mouthpieces for the scoops of a dredging machine were, for sake of convenience, cast as flat plates of the peculiar shape required, and were bent afterward into the proper form to fit the scoop. The unhammered malleable iron has a tensile strength of 41,000 lbs., and steel in the same condition 63,000 lbs., this being the mean of eight different trials made at the Woolwich Arsenal. Taking the weekly produce of a pair of 7-feet converting vessels to be only 200 tons of cast-steel, their powers of production will present a curious contrast to the immense series of buildings and furnaces required to produce this quantity of cast-steel by the old process, for which purpose most extensive works would be required; for, even after the pig-iron has been made into malleable iron bars, and these bars have been kept

at a white heat for eight or ten days, and have been converted into blister-steel, the mere melting of this steel, and casting it into ingots, would require no less than 4750 crucibles, with their lids and stands, 200 workmen, 60 boys, 700 tons of hard oven coke, and 760 separate melting furnaces, costing for their erection L.31,500.

We are informed that in Sweden several companies are already using the process, the purity of their iron offering peculiar advantages in its application; and in France, Belgium, and Sardinia, it is already being carried into effect.

CHAPTER IX.

THE PRODUCTION OF STEEL.

During the last ten years a movement in advance of old customs has been going on in the manufacture of iron and steel, of so important a character as almost to constitute a revolution in the processes of conversion of crude pigs into malleable iron and steel. Since the introduction of the hot-blast there has been no important improvement in the reduction of the ores, nor is any great amount of saving likely to be effected in that process. But as regards the conversion of the iron into the malleable state, and into the varieties of steel, very important improvements have been effected during a period extending back not more than five or ten years. This is especially true of the processes for the manufacture of steel, in which the crude iron, having first been deprived of carbon in the refinery and puddling furnace, was again carbonised by being immersed in a hot bed of charcoal for a week or a fortnight. Recently it has been attempted to substitute for this roundabout method one in which the crude iron should be converted directly into steel by depriving it of its excess of carbon. This has been done in the puddling furnace, by staying the process of decarburisation at the point at which the metal retains 1 or 1·5 per cent. of

carbon, and it has also been effected by introducing currents of air in the manner described in the last chapter. To a careful study of metallurgic chemistry, and repeated mechanical tests, we are indebted for these discoveries. These, united to more perfect machinery, have already largely affected our iron manufacture, and seem likely to benefit the country and our widely extended commerce. To Mr Bessemer, amongst others, we owe the movement in this direction; and although he has not yet accomplished all he promised at the Meeting of the British Association at Cheltenham, he nevertheless set others to work as well as himself, and by indomitable perseverance and skill, he has probably done more for the new process than any one else since the days of Cort.

Notwithstanding the work—the good work—which has already been accomplished, we are still far short of that degree of perfection necessary to produce the finer qualities of iron and steel with certainty and effect. It is true that the last four or five years have effected wonderful improvements in the production and quality of iron and steel, but we are still defective in the means of producing the same quality continuously from the same ore and fuel. For example, an order is given for a quantity of steel or iron plates, with regard to which it is essential that the whole should be as nearly as possible uniform in strength and character, and that none of the plates should be under a certain standard tenacity. It is true that numerous samples will reach the standard; but, on the other hand, one plate in a hundred of inferior quality, if not detected, may, when introduced into some constructions, lead to disastrous consequences, and condemn the whole manu-

facture. In reference, therefore, to the improvements now in progress, it is essential to the interests of the iron trade that the manufacturers should study uniformity in the character of the article produced, in order that it may be raised to a high standard of excellence, in which the manufactures of this country should stand conspicuous.

Steel is a carburet of iron containing a less proportion of carbon than cast-iron by smelting. The latter, it has been seen, contains 4 or 5 per cent. of carbon, whilst in steel the proportion is only 0·5 to 1·5 per cent. Hence the direct method of obtaining steel is obviously to deprive the crude pig-iron of a part of its carbon, to reduce its amount to the requisite proportion. This direct method has already been described in the previous chapter. On the continent, and recently in this country, a modification of the puddling process is employed for the same purpose. But, notwithstanding many advantages of directness and economy, it is not yet the process most generally adopted.

In fact, the usual process, hitherto, has been the reverse of this; wrought-iron bars of the finest quality are selected, and the necessary carbon is imparted to them by "*cementation.*" In this way the purest steel is obtained. The cast-iron for this purpose must be obtained from pure ores and smelted with pure fuel; and the puddling process by which the wrought-iron bars are produced tends to eliminate injurious alloys. Thus manufactured, the iron is in the best condition for manufacturing a pure steel, capable of taking the finest edge and the greatest degree of hardness.

I. THE PROCESS OF CEMENTATION.

To obtain steel by this process the purest wrought-iron

bars are selected, foreign bars being preferred. Down to a recent period, Swedish and Russian bars were almost exclusively employed, notwithstanding their high price; these, smelted by charcoal, have a manifest superiority over all the irons of this country, where the ores are poorer and the charcoal scarcely to be obtained. These irons, therefore, are still preferred by the steel manufacturer, being employed where fine qualities are required. For inferior purposes, spring steel, &c., some English wrought-iron has of late been used with success.

The bars, selected with care, according to the steel to be produced, are broken into convenient lengths, and placed in layers in pots mixed with and surrounded by charcoal. These pots are subjected to an intense heat, by which the carbon is vaporised, and gradually penetrates the iron and combines with it. The heat is continued for nine to eleven days, after which the bars are removed, and often present a blistered surface. Hence this quality is termed "blistered steel."

The furnaces in which the cementation is effected is shown in fig. 56; *a a* are the *pots* in which the steel is placed, 12 feet long and 3 feet square, composed of a refractory siliceous fire-stone or fire-brick. Two of these pots are placed side by side, with the grate *g*, of equal length, between them. They need to be supported on massive foundations, to avoid sinking and fracture; and they are arched over by fire-brick in such a manner that the flame passes between, under, and around them on every side. In the arch covering them, there are openings, *c c*, into the lofty dome-shaped chimney *C*, which covers all. The pots hold during each heat 15 or 16 tons

of iron, and fourteen or sixteen heats are obtained in each per annum.

In filling these pots, the converter gets into the pot and spreads a layer of charcoal over the bottom. His assistant then hands him in the bars, which he spreads in an even layer, making allowance for expansion. Over them is spread a layer of charcoal dust, and then a second layer of bars, and so on till the pot is filled; a layer of four or five inches of loam or wheelswarf is rammed over all, and the pot is ready for heating.

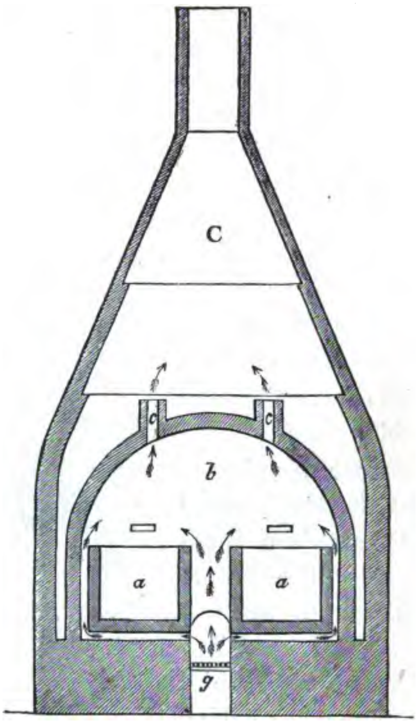


Fig. 56.

Each chest has an opening in which test-bars are laid, so that they can be withdrawn during the process of cementation, and the amount of carburisation ascertained. The appearance of the test-bars is a sufficient guide to a skilful converter as to the degree of carburisation which has been effected.

The steel thus obtained is known as *blister steel;* the bars, from the nature of the process, are hardest outside,

and are therefore unfit for immediate use, except for a few purposes, such as for files, shovels, &c.

Cast Steel consists of the bars of blister steel broken up and placed in crucibles, melted and cast into ingots. The crucibles are placed in a simple melting furnace, holding six, twelve, or more pots, a cross section of which is shown in fig. 57; *g* is the grate, *c* the crucible with its cover, *a* the chimney-stack, *b* a loose cover over the opening in the furnace, through which the pots are inserted and withdrawn. The pots having been placed in position, and raised to a white heat, the blister steel is inserted, the cover put on, and the furnace filled up with coke. When the steel is melted the pots are withdrawn, and the steel poured into cast-iron ingot moulds. The pots are replaced in the furnace, and receive a second and third charge, after which they are thrown aside. The steel thus obtained is very homogeneous, all the irregularities of carburisation of the blister steel having been got rid of by fusion. The ingots are worked under the tilt-hammer to the required shapes and sizes.

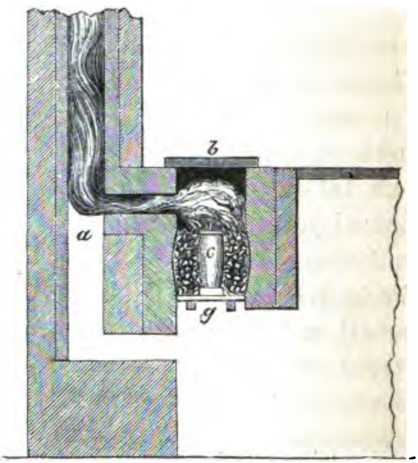


Fig. 57.

Shear Steel is blister steel cut up, piled and welded

under the tilt-hammer, the piling answering the same purpose as fusion, but less perfectly, in producing homogeneity of structure.

Double Shear Steel is single shear steel a second time cut up, piled, heated, and tilted.

Fluxes are sometimes put with the blister steel into the crucible in making cast-steel. Chloride of sodium has been used by Mr Mushet and others with a view of purifying the metal. Binoxide of manganese has also been used, though makers are not agreed as to the part it plays in the process. Steel obtained from manganiferous ores is known to be of a fine quality, but this does not appear to result from the retention of the manganese in the steel. "The most satisfactory explanation of the beneficial effect of manganese is afforded by the protracted treatment to which it is found necessary to submit iron containing much of that metal, in order to effect its proper decarbonisation, and the facility thus afforded for its complete purification."—(ABEL.) Mr Heath's process, celebrated as having been contested in every superior court in this country, is to introduce carburet of manganese into the crucible with the blister steel; but the carburet may be found in the crucible by introducing oxide of manganese and coal-tar. Metallic manganese has been used by Mr Mushet to correct red shortness or cold shortness in steel.

II. HOMOGENEOUS IRON.

For some purposes, cast-steel is produced from wrought-iron by fusion with carbon in a crucible. For this purpose, foreign selected bars are cut up and introduced into

the crucible in the ordinary steel melting furnace, fig. 57, along with a small quantity of charcoal, which, during fusion, combines with the iron. The hardness of the steel depends upon the quantity of charcoal introduced. For tool steel, 1·5 to 1·7 per cent. is introduced; for a soft steel for engraving purposes, Mr Hurst of Ramsbottom introduces less than one per cent. of charcoal with the iron, and the resulting metal is soft, receives a high polish, and casehardens without bending. This steel, or partially carburised iron, I have tested, and found to sustain a strain of 35 tons to the inch. The temperature of fusion is much higher than in melting steel, and the pots wear out correspondingly fast. A Sheffield firm have also introduced a mild steel of this kind to a considerable extent, under the name of homogeneous iron. I have found this material to take an average tensile strain of 41½ tons, or double that of wrought-iron.

III. M. CHENOT'S PROCESS.

M. Chenot's works, or rather those of M. Bugeney and Co., are in the immediate neighbourhood of Paris; and having visited them on two different occasions, I have less hesitation in giving a brief statement of this peculiar process, so far as I could gather it from M. Chenot and his son, who have the management of the works.

M. Chenot makes steel direct from the ore by converting it into a substance he calls *sponge*, in a peculiarly constructed furnace, 50 feet high and about 18 feet square at the widest part. To this furnace are attached other furnaces which contain the fires, and great care is taken that only the gaseous products of combustion come in con-

tact with the ores. The large furnace is constructed with numerous intersecting flues to distribute the heated currents from the attached furnaces, and to equalise the temperature at those parts where they come in contact with the ores.

It requires five days to convert the ore into sponge, and every twenty-four hours 18 cwt. or a ton are withdrawn from the furnace by a moveable grated platform, which rises by rack and pinions to the requisite height in the furnace, where it receives the charge, and is lowered at the required temperature to the space prepared for its reception below. Great care is taken to shut out the air by a luting of sand and clay all round the platform over which the sponge is removed from the furnace.

The ore being thus calcined or converted into sponge, it is allowed to soak in oil or any other fatty substance calculated to supply it with carbon. After this it is placed in wrought-iron retorts, and exposed for a couple of hours to the heat of a furnace in order to carry off any excess of carbon which it may have received. The sponge is next reduced to powder, and then compressed by machinery into bars in strong iron tubes. In this state it is fit for melting, and being placed in a crucible, with four tons of coke to one of steel, it is thence run into ingots. Lastly, it is prepared for the market in the usual way under the hammer. On the quality of this manufacture I can speak with some certainty, having brought several specimens home with me; and, judging from these, I can safely pronounce the Chenot manufacture a superior description of steel.

IV. PROCESS OF CAPTAIN UCHATIUS.

In this process cast-steel is produced direct from crude iron. The pigs are melted in a cupola, whence they are run into a cistern of cold water, and granulated by striking a rapidly revolving dash wheel. The finely divided particles thus obtained are mixed with pulverised oxide of iron, or sparry iron and fine clay; these having been intimately mixed, are introduced into a crucible and fused in the steel melting furnace. The granules of cast-iron, surrounded by rich oxides, yield up part of their carbon, and a slag is formed which purifies the steel. Part of the oxides are reduced, so that the quantity of steel obtained exceeds by 6 per cent. the cast-iron introduced.

The degree of hardness of the resulting cast-steel depends in a great measure on the size of the granules, the smallest granules producing the softest steel, because the decarburisation proceeds very slowly inwards from the surface. The oxidising materials employed in the crucible are either very rich hæmatite ores or pure spathose ores finely pulverised, 20 or 30 per cent. being introduced according to the amount of oxygen required.

V. GERMAN REFINING PROCESSES.

In Styria, Carinthia, Thuringia, and other parts of the Continent, steel is produced from crude-iron by the decarburising effect of a blast in a furnace similar to a refinery. The pigs are melted by charcoal, and a strong blast allowed to play over the molten surface. The converter stirs up the iron to bring fresh portions under the action of the blast, until he judges by the consolidation of the

mass and the colour of the flame that the process has been carried far enough.

VI. PRODUCTION OF STEEL BY PUDDLING.

For five-and-twenty years past it has been well known that steel could be produced direct from cast-iron in the puddling furnace, by stopping the process of decarburisation before the whole of the carbon had been eliminated; but it is only recently that the manufacture has assumed much commercial importance. The furnace employed is similar to that figured at page 92 for puddling iron, or may be constructed with hollow cast-iron blocks, through which a circulation of water is maintained, surrounding the hearth, and with an extra chamber for heating the pigs, as shown in figs. 58 and 59. The method of operat-

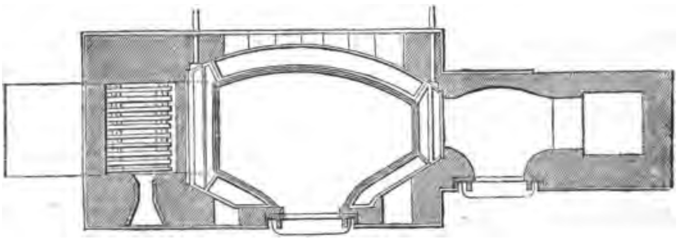


Fig. 58.

ing is similar to that for puddling iron, already described; the difference being that in the latter case the molten iron is exposed to the oxidising action of the flame, until as far as possible the whole of the carbon originally in it is eliminated, whilst in the production of puddled steel the process is stopped before that point is reached, and whilst the iron retains from ½ to 1 per cent. of carbon. It is

only by experience that the puddler learns by the appearance of the grains, the consolidation of the mass, and the

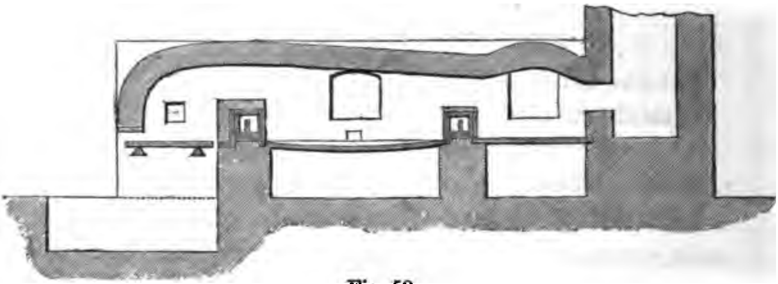


Fig. 59.

colour of the flame, the precise condition of carburisation of the materials in the furnace. When this knowledge has been attained, various qualities of steel, softer or harder, can be produced at will with great certainty. As soon as the desired degree of carburisation is reached, the damper is shut, the steel collected into balls, and hammered and rolled in the usual way. The bars thus obtained may be broken and the fractures examined, in order that any mistakes in the manufacture may be corrected by the rejection of bad bars. The selected bars are then piled, heated, and rolled into bars or plates as may be required.

By a careful superintendence of the manufacture, and the selection of proper iron for the process—the North Welsh, Hæmatite, and best Scotch brands being preferred—a tough malleable steel is produced, unfit for cutting instruments, but capable of replacing wrought-iron in many constructions where strength and lightness are desired. It has been introduced already to a considerable extent in boiler-making and ship-building, and attempts have been made to apply it to bridges. The milder quali-

ties have a tenacity of 35 tons per square inch, and the harder qualities rather above 40 tons per square inch. Its cost is about 25 per cent. greater than that of wrought iron, owing to a somewhat greater difficulty in working it under the hammer and in the rolls.

VII. MR MUSHET'S PROCESS.

I have had an opportunity of testing the strength of some specimens of gun-metal produced by Mr Mushet, which belong rather to the class of steel than of iron, and the results of which are given in the next chapter. The process by which this metal is produced is not known, but the following particulars have been communicated by Mr Mushet.

Bar iron is cut up into pieces of about one ounce weight. These are melted in steel melting-pots, with a small proportion of two other metals, from which the gun-metal derives its peculiar properties. The hardness of the alloy is regulated by adding a certain proportion of charcoal. After fusion the alloy is poured into moulds, and a bloom or ingot of gun-metal is obtained.

The softer varieties can be welded like cast-steel, but not the harder varieties, and its tenacity in all cases is impaired by raising it to a welding temperature. It ought therefore to be rolled or drawn out at a cast-steel heat.

CHAPTER X.

THE STRENGTH AND OTHER MECHANICAL PROPERTIES OF CAST AND WROUGHT IRON AND STEEL.

In this section we have to consider the tensile and transverse strengths and powers of resisting compression of cast and malleable iron, as determined by direct experiment upon specimens of the material; and also to examine whether, as has been alleged, the hot-blast process injures the tenacity of the metal.

CAST-IRON.

The following tables give the results of experiments undertaken by Professor Hodgkinson and myself at the request of the British Association, to determine the tensile and transverse strengths of cast-iron derived from the hot and cold blast. The castings for ascertaining the tensile strain were made very strong at the ends, with eyes for the bolts to which the shackles were attached; the middle part, where it was intended that the specimen should break, was cast of a cruciform + transverse section. The four largest castings were broken by the chain-testing machine belonging to the Corporation of Liverpool, the others by a lever.

TABLE I.—*Results of Experiments on the Tensile Strength of Cast-iron.*

Description of Iron.	Number of Experiments.	Mean strength per square inch of section.	
		lbs.	tons cwts.
Carron iron, No. 2, hot-blast	3	13,505	6 0½
" " cold-blast	2	16,683	7 9
" No. 3, hot-blast	2	17,755	7 18¼
" " cold-blast	2	14,200	6 7
Devon (Scotland) iron, No. 3, hot-blast.	1	21,907	9 15½
Buffery iron, No. 1, hot-blast	1	13,434	6 0
" " cold-blast	1	17,466	7 16
Coed-Talon (North Wales) iron, No. 2, hot-blast . .	2	16,676	7 9
Do. do. cold-blast . .	2	18,855	8 8

From the same series of experiments we select the following tables, givingthe results obtained in regard to the resistance opposed to compression by cast-iron. The specimens employed were cylinders and prisms of various dimensions, and having their faces turned accurately parallel to each other and perpendicular to the axis of the specimen. They were crushed by a lever between parallel steel discs.

TABLE II.—*Weights required to crush Cylinders, &c., of Carron Iron, No. 2, Hot-blast.*

Diameter of Cylinder in parts of an inch.	Number of Experiments.	Mean Crushing Weight.	Mean Crushing Weight per square inch.	General Mean per square inch.
		lbs.	lbs.	
¼	3	6,426	130,909	121,685 lbs. =54 tons 6¼ cwt.
⅜	4	14,542	131,665	
½	5	22,110	112,605	
$\frac{16}{25}$ = ·64	1	35,888	111,560	
Prism, base ·50 inch square	3	25,104	100,416	100,738 lbs. =44 tons 19¼ cwt.
Prism, base 1·00 × ·26	2	26,276	101,062	

TABLE III.—*Weights required to crush Cylinders, &c., of Carron Iron, No. 2, Cold-blast.*

Diameter of Cylinder in parts of an inch.	Number of Experiments.	Mean Crushing Weight.	Mean Crushing Weight per square inch.	General Mean per square inch.
		lbs.	lbs.	
$\frac{1}{4}$	2	6,088	124,023	125,403 lbs. = 55 tons 19¼ cwt.
$\frac{3}{8}$	4	14,190	128,478	
$\frac{1}{2}$	7	24,290	123,708	
Equilateral triangle side ·866 . . .	2	32,398	99,769	100,631 lbs. = 44 tons 18¼ cwt.
Squares, side $\frac{1}{2}$ inch	2	24,538	98,152	
Rectangles, base 1·00 inch × ·243	3	26,237	107,971	
Cylinders, ·45 inch diameter and ·75 inch high . . .	2	15,369	96,634	

TABLE IV.—*Results of Experiments to ascertain the Force necessary to crush short Cylinders, &c., of Cast-iron from various parts of the United Kingdom.*

Description of Iron.	Number of Experiments.	Mean Crushing Weight per square inch.	
		lbs.	tons cwt.
Devon (Scotch) iron, No. 3, hot-blast, ...	2	145,435	64 18½
Buffery iron, No. 1, hot-blast	4	86,397	38 11¼
" " cold-blast	4	93,385	41 13½
Coed Talon, No. 2, hot-blast	4	82,734	36 18½
" " cold-blast	4	81,770	36 10
Carron iron, No. 2, hot-blast	2	108,540	48 9
" " cold-blast	3	106,375	47 9¾
Carron iron, No. 3, hot-blast	3	133,440	59 11¼
" " cold-blast	4	115,442	51 10¾

The specimens of Carron iron in Table IV. were prisms whose base was $\frac{3}{4} \times \frac{1}{3} = \frac{1}{4}$ square inch, and whose height varied from $\frac{1}{2}$ inch to 1 inch. The other specimens were cylinders, whose diameters were about $\frac{1}{2}$ inch, and height varied from $\frac{1}{2}$ inch to 2 inches.

From the above experiments, Mr Hodgkinson concludes that "where the length is not more than about three times the diameter, the strength for a given base is pretty nearly the same." Fracture took place either by wedges sliding off (fig. 60), or by the top and bottom forming pyramids, and forcing out the sides (fig. 61); and the angle of the wedge is nearly constant, a mean of 21 cylinders being 55° 32′.

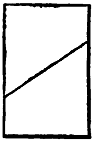


Fig. 60.

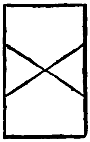


Fig. 61.

From the same series of experiments I give the results obtained by myself, in regard to the effects of time and temperature. The bars employed were cast to be 1 inch square, and 4 feet 6 inches long, and were loaded with permanent weights as under; the deflections being taken at various intervals during a period of fifteen months. Coed-Talon hot and cold blast iron was employed.

TABLE V.—*The Effect of Time on loaded Bars of Hot and Cold Blast Iron, in their Resistance to a Transverse Strain.*

Permanent load in lbs.	Increase of Deflection of Cold-blast bars.	Increase of Deflection of Hot-blast bars.
280	·033	·043
336	·046	·077
392	·140	·088
449	·047	...
Mean.	·066	·069

It has been assumed by most writers on the strength of materials, that the elasticity of cast-iron remained perfect to the extent of one-third the weight that would break it. This is, however, a mere assumption, as it has

been found that the elasticity of cast-iron is injured with less than one-half that weight, and the question to be solved in the above experiments was, to what extent the material could be loaded without endangering its security; or how long it would continue to support weights, varying from one-half to one-tenth of the load that would produce fracture. These experiments were continued from six to seven years, and the results obtained were, that the bars which were loaded to within one-tenth of their breaking weight, would have continued to have borne the load, in the absence of any disturbing clause, *ad infinitum;* but the effect of change, either of the same or a lighter load, led ultimately to a fracture.

From these facts it is deduced, that so long as the molecules of the material are under strain (however severe that strain may be), they will arrange and accommodate themselves to the pressure, but with the slightest disturbance, whether produced from vibration or the increase or diminution of load, it becomes, under these influences, only a question of time when rupture ensues.

In the following experiments on the relative strengths of Coed-Talon hot and cold blast iron to resist transverse strain at different temperatures, the results are reduced to those of bars 2 feet 3 inches between supports, and 1 inch square.

From this table it will be seen "that a considerable failure of the strength took place after heating the No. 2 iron from 26° to 190°. At 212°, we have in the No. 3 a much greater weight sustained than by No. 2 at 190°; and at 600° there appears, in both hot and cold-blast, the anomaly of increased strength as the temperature is in-

TABLE VI.—*Effect of Temperature on the Transverse Strength of Cast-iron.*

	Temperature, Fahr.	Specific Gravity.	Modulus of Elasticity.	Breaking Weight.	Ultimate Deflection.	Power of resisting impact.
Cold Blast, No. 2	27°	6·955	12799050	874·0	·4538	397·7
"	32	6·955	14327450	949·6	·402	382·4
"	113	6·955	14168000	812·9	·336	273·1
Hot Blast, No. 2	20	6·968	14902900	811·7	·4002	325·0
"	32	6·968	14003350	919·7	·429	395·0
"	84	6·968	14500000	877·5	·421	369·4
Cold Blast, No 2	192	...	14398600	743·1	·301	223·7
No. 3	212	...	...	924·5		
"	600	...	...	1033·0		
No. 2	Red by daylight	...	...	663·3		
"	Red in dark	...	...	723·1		
Hot Blast, No. 2	136	...	13046200	875·7	·389	340·6
"	187	...	11012500	638·8	·359	229·3
"	188		13869500	823·6	·363	298·9
No. 3	212	...	...	818·4		
"	600	...	...	875·8		
No. 2	Red in dark	...	...	829·7		

creased."* The above results are, with one exception, in favour of the cold blast, as far as strength is concerned; and in favour of the hot blast, with one exception, as regards power of resisting impact.

The following table gives the results of my own experiments on the transverse strength of rectangular cast-iron bars, each bar being reduced to exactly one inch square.

"In the following abstract, the transverse strength, which may be taken as a criterion of the value of each iron, is obtained from the mean of the experiments first on the long bars, 4 feet 6 inches between the supports, and next on those of half the length, or 2 feet 3 inches between supports."

"All the other values are deduced from the 4 feet 6 inches bars."

* This probably arises from the greater ductility of the bars at an increased temperature.

TABLE VII.—*General Summary of Results on Rectangular Bars, as obtained from nearly the whole of the British Iron-Works.—"Manchester Memoirs," New Series, Vol. V.*

No. of iron in the scale of strength.	Description of Iron.	No. of Experiments on each.	Specific Gravity.	Modulus of Elasticity in lbs. per square inch, or stiffness.	Breaking weight in lbs. of bars 4 ft. 6 in. between supports.	Breaking weight in lbs. of bars 2 ft. 5 in., reduced to 4 ft. 6 in. between supports.	Mean breaking weight in lbs. (S.)	Ultimate deflection of 4 ft. 6 in. bars in parts of an inch.	Power of the 4 ft. 6 in. bars to resist impact.	Colour.	Quality.
1	Ponkey, No. 3, cold-blast . .	4	7·122	17,211,000	567	595	581	1·747	992	Whitish grey	Hard
2	Devon, No. 3, hot-blast* . .	2	7·251	22,473,650	537	...	537	1·090	589	White	"
3	Oldberry, No. 3, hot-blast . .	5	7·300	22,733,400	543	517	530	1·005	549	"	"
4	Carron, No. 3, hot-blast* . .	2	7·056	17,873,100	520	534	527	1·365	710	Whitish grey	"
5	Eglinton, No. 4, from prepared coke†	6	...	...	515	...	515	1·460	751	Light grey	Rather hard
6	Beaufort, No. 3, hot-blast . .	5	7·069	16,802,000	505	529	517	1·599	807	Dullish grey	Hard
7	Butterley	4	7·038	15,379,500	489	515	502	1·815	889	Dark grey	Soft
8	Bute, No. 1, cold-blast . . .	4	7·066	15,163,000	495	487	491	1·764	872	Bluish grey	"
9	Windmill End, No. 2, cold-blast .	4	7·071	16,490,000	483	495	489	1·581	765	Dark grey	Hard
10	Old Park, No. 2, cold-blast . .	5	7·049	14,607,000	441	529	485	1·621	718	Grey	Soft
11	Beaufort, No. 2, hot-blast . .	4	7·108	16,301,000	478	470	474	1·512	729	Dull grey	Hard
12	Low Moor, No. 2, cold-blast . .	4	7·055	14,569,500	462	483	472	1·852	855	Dark grey	Soft
13	Buffery, No. 1, cold-blast* . .	5	7·079	15,381,200	463	...	463	1·550	721	Grey	Rather hard
14	Brimbo, No. 2, cold-blast . .	5	7·017	14,911,666	466	453	459	1·748	815	Light grey	"
15	Apedale, No. 2, hot-blast, . .	8	7·017	14,852,000	457	455	456	1·730	791	"	Stiff
16	Oldberry, No. 2, cold-blast, . .	4	7·059	14,307,500	453	457	455	1·811	822	Dark grey	Rather soft
17	Pentwyn, No. 2	4	7·038	15,193,000	438	473	455	1·484	650	Bluish grey	Hard
18	Maesteg, No. 2	5	7·038	13,959,500	453	455	454	1·957	886	Dark grey	Rather soft
19	Muirkirk, No. 1, cold-blast* . .	4	7·113	14,003,550	443	464	453	1·734	770	Bright grey	Fluid
20	Adelphi, No. 2, cold-blast . .	5	7·080	13,815,500	441	457	449	1·759	777	Light grey	Soft
21	Blania, No. 3, cold-blast . .	5	7·159	14,281,466	433	464	448	1·726	747	Bright grey	Hard
22	Devon, No. 3, cold-blast . .	4	7·285	22,907,700	448	...	448	0·790	353	Light grey	"
23	Gartsherrie, No. 3, hot-blast .	5	7·017	13,894,000	427	467	447	1·557	998	"	Soft
24	Eglinton, No. 4, common coke .	6	...	...	447	...	447	1·870	798	Dull grey	Rather hard
25	Frood, No. 2, cold-blast . .	5	7·031	13,112,666	460	434	447	1·825	541	Light grey	Open

26	Lane End, No. 2	3	7·028	15,787,666	444	...	444	1·414	629	Dark grey	Soft
27	Carron, No. 3, cold-blast	5	7·094	16,246,966	444	443	443	1·336	593	Grey	,,
28	Dundyvan, No. 3, cold-blast	4	7·087	16,534,000	456	430	443	1·469	674	Dull grey	Rather soft
29	Maesteg (marked red)	5	7·038	13,971,500	440	444	442	1·887	830	Bluish grey	Fluid
30	Corbyns Hall, No. 2	5	7·007	13,845,866	430	454	442	1·687	727	Grey	Soft
31	Pontypool, No. 2	5	7·080	13,136,500	439	441	440	1·857	816	Dull blue	Rather soft
32	Walbrook, No. 3	5	6·979	15,394,766	432	449	440	1·443	625	Light grey	Rather hard
33	Milton, No. 3, hot-blast	4	7·051	15,852,500	427	449	438	1·368	585	Grey	,,
34	Buffery, No. 1, hot-blast*	3	6·998	13,730,500	436	...	436	1·640	721	Dull grey	Soft
35	Level, No. 1, hot-blast	5	7·080	15,452,500	461	403	432	1·516	699	Light grey	,,
36	Pant, No. 2,	5	6·975	15,280,900	408	455	431	1·251	511	,,	Rather hard
37	Level, No. 2, hot-blast	6	7·031	15,241,000	419	439	429	1·358	570	Dull grey	Soft
38	W. S. S., No. 2	5	7·041	14,953,333	413	446	429	1·339	554	Light grey	,,
39	Eagle Foundry, No. 2, hot-blast	4	7·038	14,211,000	408	446	427	1·512	618	Bluish grey	,,
40	Elsicar, No. 2, cold-blast	4	6·928	12,586,500	446	408	427	2·227	992	Grey	,,
41	Varteg, No. 2, hot-blast	4	7·007	15,012,000	422	430	426	1·450	621	,,	Hard
42	Coltham, No. 1, hot-blast	5	7·128	15,510,066	464	385	424	1·532	716	Whitish grey	Rather soft
43	Carrol, No. 2, cold-blast	4	7·069	17,036,000	430	408	419	1·231	530	Grey	Hard
44	Muirkirk, No. 1, hot-blast*	4	6·953	13,294,400	417	...	418	1·570	656	Bluish grey	Soft
45	Brierley, No. 2	5	7·185	16,156,133	406	...	418	1·222	494	Dark grey	,,
46	Coed-Talon, No. 2, hot-blast*	4	6·969	14,322,500	409	424	416	1·882	771	Bright grey	,,
47	Coed-Talon, No. 2, cold-blast*	5	6·955	14,304,000	403	418	413	1·470	600	Grey	,,
48	Monkland, No. 2, hot-blast	3	6·916	12,259,500	402	404	403	1·762	709	Bluish grey	,,
49	Ley's Works, No. 1, hot-blast	3	6·957	11,539,333	392	...	392	1·890	742	,,	,,
50	Milton, No. 1, hot-blast	4	6·976	11,974,500	353	386	369	1·525	532	Grey	Soft and fluid
51	Plas Kynaston, No. 2, hot-blast	5	6·916	13,341,633	378	337	357	1·366	517	Light grey	Rather soft

* The irons with asterisks are taken from the experiments on hot and cold blast iron made by Mr Hodgkinson and Mr Fairbairn for the British Association for the Advancement of Science. See Seventh Report, vol. vi.

The modulus of elasticity was usually taken from the deflection caused by 112 lbs. on the 4 feet 6 inch bars.

To find from the above the breaking weight in rectangular bars generally: calling b and d the breadth in inches, and l the distance between the supports in feet; and putting 4·5 for 4 feet 6 inches, we have $\frac{4{\cdot}5\, b\, d^2\, S}{l}$ = breaking weight in lbs. The value of S being taken from the table above.

For example:—What weight would be necessary to break a bar of Lowmoor iron, 2 inches broad, 3 inches deep, and 6 feet between the supports? According to the rule given above, we have $b=2$ inches, $d=3$ inches, $l=6$ feet, $S=472$, by the table. Then

$$\frac{4{\cdot}5 \times b\, d^2\, S}{l} = \frac{4{\cdot}5 \times 2 \times 9 \times 472}{6} = 6372 \text{ lbs.}$$

† This iron was melted in the cupola, from coke entirely freed from sulphur, by Mr Crace Calvert's process.

With regard to the comparative strengths of hot and cold blast iron, the following extracts from Mr Hodgkinson's report, read before the British Association, give the general results of his experiments:—

TABLE VIII.—*Carron Iron*, No. 2.

	Cold-blast.	Hot-blast.	Ratio representing Cold-blast by 1000.
Tensile strength in lbs. per inch square	16683 (2)	13505 (3)	1000 : 809
Compressive do. in lbs. per inch, from castings torn asunder	106375 (3)	108540 (2)	1000 : 1020 } Mean 997.
Do. from prisms of various forms . .	100631 (4)	100738 (2)	1000 : 1001 } Mean 997.
Do. from cylinders . .	125403 (13)	121685 (13)	1000 : 970 } Mean 997.
Transverse strength from all the experiments	(11)	(13)	1000 : 991
Power to resist impact	(9)	(9)	1000 : 1005
Transverse strength of bars 1 inch square in lbs.	476 (3)	463 (3)	1000 : 973
Ultimate deflection of do. in inches . .	1·313 (3)	1·337 (3)	1000 : 1018
Modulus of elasticity in lbs. per square inch	17270500 (2)	16085000 (2)	1000 : 931
Specific gravity . . .	7066	7046	1000 : 997

TABLE IX.—*Devon Iron*, No. 3.

	Cold-blast.	Hot-blast.	Ratio representing Cold-blast by 1000.
Tensile strength . .	...	21907 (1)	
Compressive do. . .	...	145435 (4)	
Transverse do. from the experiments generally	(5)	(5)	1000 : 1417
Power to resist impact	(4)	(4)	1000 : 2786
Transverse strength of bars 1 inch square	448 (2)	537 (2)	1000 : 1199
Ultimate deflection do.	79 (2)	1·09 (2)	1000 : 1380
Modulus of elasticity do.	22907700 (2)	22473650 (2)	1000 : 981
Specific gravity . . .	7·295 (4)	7·229 (2)	1000 : 991

TABLE X.—*Buffery Iron*, No. 1.

Tensile strength . . .	17466 (1)	13434 (1)	1000 : 769
Compressive do. . . .	93366 (4)	86397 (4)	1000 : 925
Transverse do. . . .	(5)	(5)	1000 : 931
Power to resist impact .	(2)	(2)	1000 : 963
Transverse strength of bars one inch square	463 (3)	436 (3)	1000 : 942
Ultimate deflection do.	1·55 (3)	1·64 (3)	1000 : 1058
Modulus of elasticity do.	15381200 (2)	13730500 (2)	1000 : 893
Specific gravity . . .	7·079	6·998	1000 : 989

TABLE XI.—*Coed-Talon Iron*, No. 2.

Tensile strength . . .	18855 (2)	16676 (2)	1000 : 884
Compressive do. . . .	81770 (4)	82739 (4)	1000 : 1012
Specific gravity . . .	6·955 (4)	6·968 (3)	1000 : 1002

TABLE XII.—*Carron Iron*, No. 3.

Tensile strength . . .	14200 (2)	17755 (2)	1000 : 1250
Compressive do. . . .	115442 (4)	133440 (3)	1000 : 1156
Specific gravity . . .	7·135	7·056 (1)	1000 : 989

"Beginning with No. 1 iron, of which we have a specimen from the Buffery Iron-Works, a few miles from Birmingham, we find the cold-blast iron somewhat surpassing the hot-blast in all the following particulars: direct tensible strength, compressive strength, transverse strength, power to resist impact, modulus of elasticity or stiffness, specific gravity; whilst the only numerical advantage possessed by the hot-blast iron is, that it bends a little more than the cold-blast before it breaks.

"In the irons of the quality No. 2, the case seems in some degree different; in these the advantages of the rival kinds seems to be more nearly balanced. They are still, however, rather in favour of the cold-blast.

"So far as my experiments have proceeded, the irons of No. 1 have been deteriorated by the hot-blast; those of No. 2 appear also to have been slightly injured by it; while the irons of No. 3 seem to have benefited by its mollifying powers. The Carron iron, No. 3, hot-blast, resists both tension and compression with considerably more energy than that made with the cold-blast; and the No. 3 hot-blast iron from the Devon Works, in Scotland, is one of the strongest cast-irons I have seen, whilst that made by the cold-blast is comparatively weak, though its specific gravity is very high, and higher than in the hot. The extreme hardness of the cold-blast Devon iron alone prevented many experiments that would otherwise have been made upon it, no tools being hard enough to form the specimens. The difference of strength in the Devon irons is peculiarly striking.

"From the evidence here brought forward, it is rendered exceedingly probable that the introduction of a heated blast in the manufacture of cast-iron has injured the softer irons, whilst it has frequently mollified and improved those of a harder nature; and, considering the small deterioration that the irons of quality No. 2 have sustained, and the apparent benefit to those of No. 3, together with the great saving effected by the heated blast, there seems good reason for the process becoming as general as it has done."

The following table gives a summary of the relative compressive and tensile resistances of various descriptions of iron, as they have been determined by Professor Hodgkinson:—

TABLE XIII. – *Tensile and Compressive Strength of various descriptions of Iron.*

Description of the Iron.	Tensile strength per square inch of section.		Height of Specimen.	Crushing strength per square inch of section.		Ratio of the powers to resist tension and compression.	
	lbs.	tons.	inch.	lbs.	tons.		Mean.
Low Moor Iron, No. 1	12,694 =	5·667	¾	64,534 =	28·809	1 : 5·084	1 : 4·765
			1½	56,455 =	25·198	1 : 4·446	
Low Moor Iron, No. 2	15,458 =	6·901	¾	99,525 =	44·430	1 : 6·438	1 : 6·205
			1½	92,332 =	41·219	1 : 5·973	
Clyde Iron, No. 1 .	16,125 =	7·198	¾	92,869 =	41·459	1 : 5·759	1 : 5·631
			1½	88,741 =	39·616	1 : 5·503	
Clyde Iron, No. 2 .	17,807 =	7·949	¾	109,992 =	49·103	1 : 6·177	1 : 5·953
			1½	102,030 =	45·549	1 : 5·729	
Clyde Iron, No. 3 .	23,468 =	10·477	¾	107,197 =	47·855	1 : 4·568	1 : 4·518
			1½	104,881 =	46·821	1 : 4·469	
Blaenavon Iron, No. 1	13,938 =	6·222	¾	90,860 =	40·562	1 : 6·519	1 : 6·149
			1½	80,561 =	35·964	1 : 5·780	
Blaenavon Iron, No. 2, first sample	16,724 =	7·466	¾	117,605 =	52·502	1 : 7·032	1 : 6·577
			1½	102,408 =	45·717	1 : 6·123	
Blaenavon Iron, No. 2, second sample	14,291 =	6·380	¾	68,559 =	30·606	1 : 4·797	1 : 4·796
			1½	68,532 =	30·594	1 : 4·795	
Calder Iron, No. 1 .	13,735 =	6·131	¾	72,193 =	32·229	1 : 5·256	1 : 5·394
			1½	75,983 =	33·921	1 : 5·532	
Coltness Iron, No. 3 .	15,278 =	6·820	¾	100,180 =	44·723	1 : 6·557	1 : 6·611
			1½	101,831 =	45·460	1 : 6·665	
Brymbo Iron, No. 1 .	14,426 =	6·440	¾	74,815 =	33·399	1 : 5·186	1 : 5·216
			1½	75,678 =	33·784	1 : 5·246	
Brymbo Iron, No. 3 .	15,508 =	6·923	¾	76,133 =	33·988	1 : 4·909	1 : 4·936
			1½	76,958 =	34·356	1 : 4·963	
Bowling Iron, No. 2 .	13,511 =	6·032	¾	76,132 =	33·987	1 : 5·635	1 : 5·555
			1½	73,984 =	33·028	1 : 5·476	
Ystalyfera Anthracite Iron, No. 2	14,511 =	6·478	¾	99,926 =	44·610	1 : 6·886	1 : 6·735
			1½	95,559 =	42·660	1 : 6·585	
Yniscedwyn Anthracite Iron, No. 1	13,952 =	6·228	¾	83,509 =	37·281	1 : 5·985	1 : 5·811
			1½	78,659 =	35·115	1 : 5·638	
Yniscedwyn Anthracite Iron, No. 2	13,348 =	5·959	¾	77,124 =	34·430	1 : 5·778	1 : 5·712
			1½	75,369 =	33·646	1 : 5·646	
Mr Morries Stirling's Iron, denominated second quality	25,764 =	11·502	¾	125,333 =	55·952	1 : 4·865	1 : 4·751
			1½	119,457 =	53·329	1 : 4·637	
Mr Morries Stirling's Iron, denominated third quality	23,461 =	10·474	¾	158,653 =	70·827	1 : 6·762	1 : 6·149
			1½	129,876 =	57·980	1 : 5·536	

The following table gives a general summary of the results of my own experiments on the strength of iron after successive meltings. The iron used was Eglinton No. 3, hot-blast, and was melted eighteen times, three

bars being cast at each melting. These bars, which were about 1 inch square and 5 feet long, were placed upon supports 4 feet 6 inches apart, and broken by a transverse strain. Cubes, from the same irons, exactly 1 inch square, were then crushed between parallel steel bars, by a large wrought-iron lever.

In the following Table XIV., the results on transverse strain are reduced to those on bars exactly 1 inch square and 4 feet 6 inches between supports.

Table XIV.—*Transverse Strength of Iron after successive Remeltings.*

No. of melting.	Specific gravity.	Mean breaking weight in lbs.	Mean ultimate deflection in inches.	Power to resist impact.	Mean crushing weight of inch cubes in tons.
1	6·969	490·0	1·440	705·6	41·9
2	6·970	441·9	1·446	630·9	
3	6·886	401·6	1·486	596·7	
4	6·938	413·4	1·260	520·8	
5	6·842	431·6	1·503	648·6	
6	6·771	438·7	1·320	579·0	
7	6·879	449·1	1·440	646·7	
8	7·025	491·3	1·753	861·2	
9	7·102	546·5	1·620	885·3	64·3
10	7·108	566·9	1·626	921·7	
11	7·113	651·9	1·636	1066·5	
12	7·160	692·1	1·666	1153·0	
13	7·134	634·8	1·646	1044·9	
14	7·530	603·4	1·513	912·9	
15	7·248	371·1	0·643	238·6	82·8
16	7·330	351·3	0·566	198·5	
17	lost.				
18	7·385	312·7	0·476	148·8	

In the above results it will be observed that the maximum of strength, elasticity, &c., is only arrived at after the metal has undergone twelve successive meltings. It is probable that other metals and their alloys may follow the same law, but that is a question that has yet to be solved, probably by a series of experiments requiring

a considerable amount of time and labour to accomplish, but which I venture to hope I may be able at some future time to undertake.

In the resistance of the different meltings from the same iron, to a force tending to crush them, we have the following results:—

TABLE XV.—*Compressive Strength of Iron after successive Remeltings.*

Number of meltings.	Resistance to compression per square inch, in tons.	Remarks.
1	44·0	
2	43·6	
3	41·1	
4	40·7	
5	41·1	
6	41·1	
7	40·9	
8	41·1	
9	55·1	
10	57·7	
11, 11	Mean 69·8	
12	73·1	In this experiment the cube did not bed properly on the steel plates, otherwise it would have resisted a much greater force.
13	66·0	
14	95·9	
15	76·7	
16	70·5	
18	88·0	

Nearly the whole of the specimens were fractured by wedges which split or slid off diagonally at an angle of from 52° to 58.

Power to Resist Torsion.

The following experiments were made by the American Government on the torsional strength of iron cast in various forms. The distance between the keys which secure

the ends of the bar when strained was 15 inches. The length of that part of the bar subject to torsion was about 8 diameters. It appeared that the force requisite to give the bar a permanent set of $\frac{1}{2}°$ is about 9-10ths of that which will break it. With wrought-iron they found that with forces not producing a permanent set, its capacity to resist torsional deflection is equal to that of cast-iron. But set commences with a less strain in wrought than in cast iron, and the material yields more readily thereafter. The mean value of the strain giving a set of $\frac{1}{2}°$ in wrought-iron is about 6-10ths the mean value of the strain giving a like set to cast-iron. The resistance of bronze to torsion is much less than either, being about one-third that of cast-iron.

TABLE XVI.—*Mean Results on Torsion of Cast-iron.*

Description of Metal.	Fusion.	Diameter.	Angles of Permanent Set at					Breaking Weight.	Torsional Strength, $S = \frac{wr}{d^3}$		
			1000 lbs.	1500 lbs.	2000 lbs.	2500 lbs.	Maximum.		Ultimate.	At set of $\frac{1}{2}°$	Ratio.
No. 1, cast-iron	2d	1·916	0°·2	2°·2	...	...	12°·9	1737	6,176	4442	·724
	3d	1·875	0 ·0	0 ·3	3°·8	...	16 ·0	2320	8,799	6447	·733
Nos. 1 and 3, cast-iron .	2d & 3d	1·913	0 ·0	0 ·1	0 ·7	2°·4	10 ·5	2730	9,752	6611	·678
Nos. 1 and 2, cast-iron .	2d	1·927	0 ,1	0 ·9	...	...	21 ·7	2245	9,847	4723	·601
	3d	1·893	0 0	0 ·0	0 ·8	4 ·9	16 ·7	2840	10,467	7000	·669
Nos. 1, 2, and 3, cast-iron	2d	1·908	0 ·0	0 ·1	1 ·0	3 ·9	14 ·0	2697	9,711	6793	·700
	3d	1·908	0 .1	0 ·2	0 ·5	2 ·5	6 ·9	2515	9,065	7130	·786

MALLEABLE IRON.

The greatly extended application of wrought-iron to every variety of construction renders an investigation of its properties peculiarly interesting. It is now em-

ployed more extensively than cast-iron; and, on account of its ductility and strength, nearly two-thirds of the weight of material may in many cases be saved by its employment, while great lightness and durability are secured. Its superiority is especially evident in constructions where great stiffness is not required; but on the other hand any degree of rigidity may be obtained by the employment of a tubular or cellular structure, and this may be seen in the construction of wrought-iron tubular bridges, beams, and iron ships. Malleable iron, which is making such vast changes in the forms of construction, cannot but be interesting and important; and considering that the present is far from the limit of its application, we shall endeavour to give it that degree of attention which the importance of the subject demands.

From the forge and the rolling-mill we derive two distinct qualities of iron, known as "*red short*" and "*cold short.*" The former is the most ductile, and is a tough fibrous material, which exhibits considerable strength when cold; the latter is more brittle, and has a highly crystalline fracture, almost like cast-iron; but the fact is probably not generally known, that the brittle works as well, and is as ductile under the hammer as the other, when at a high temperature.

Mr Charles Hood, in a paper read some time ago before the Institute of Civil Engineers, went into the subject of the change in the internal structure of iron independently of and subsequently to the processes of its manufacture. After adducing several instances of tough fibrous malleable iron becoming crystalline and brittle during their employment, he attributes these changes to the influence

of percussion, heat, and magnetism, but questions whether either will produce the effect *per se.* Mr Hood continues: "The most common exemplification of the effect of heat in crystallising fibrous iron is, by breaking a wrought-iron furnace bar, which, whatever quality it was of in the first instance, will in a short time invariably be converted into crystallised iron, and by heating and rapidly cooling, by quenching with water a few times any piece of wrought-iron, the same effect may be far more speedily produced. In these cases we have at least two of the above causes in operation—heat and magnetism. In every instance of heating iron to a very high temperature, it undergoes a change in its electric or magnetic condition; for at very high temperatures iron loses its magnetic powers, which return as it gradually cools to a lower temperature. In the case of quenching the iron with water, we have a still more decisive assistance from the electric and magnetic forces; for Sir Humphry Davy long since pointed out that all cases of vaporisation produced negative electricity in the bodies in contact with the vapour; a fact which has lately excited a good deal of attention in consequence of the discovery of large quantities of negative electricity in effluent steam." Mr Hood then proceeds to the subject of percussion: "In the manufacture of some descriptions of hammered iron, the bar is first rolled into shape, and then one-half the length of the bar is heated in a furnace, and immediately taken to the tilt-hammer and hammered, and the other end of the bar is then heated and hammered in the same manner. In order to avoid any unevenness in the bar, or any difference in its colour where the two distinct operations have terminated, the workman fre-

quently gives the bar a few blows with the hammer upon that part which he first operated upon. That part of the bar immediately becomes crystallised, and so extremely brittle that it will break to pieces by merely throwing it on the ground, though all the rest of the bar will exhibit the best and toughest quality imaginable. This change, therefore, has been produced by percussion (as the primary agent) when the bar is at a lower temperature than the welding heat. Here it must be observed that it is not the excess of hammering which produces the effect, but the absence of a sufficient degree of heat, at the time that the hammering takes place; and the evil may probably be all produced by four or five blows of the hammer if the bar happens to be of a small size. In this case we witness the combined effects of percussion, heat, and magnetism. When the bar is hammered at the proper temperature, no such crystallisation takes place, because the bar is insensible to magnetism; but as soon as the bar becomes of that lower degree of temperature at which it can be affected by magnetism, the effect of the blows it receives is to produce magnetic induction, and that magnetic induction, and consequent polarity of its particles, when assisted by further vibrations from additional percussion, produces a crystallised texture."

The crystallisation of perfectly fibrous and ductile wrought-iron has long been a subject of dispute; and lthough we agree with most of Mr Hood's views, we are not altogether prepared to admit that the causes assigned are the only ones concerned in producing the change, or that more than one is *necessary*. On the occasion of the accident on the Versailles Railway some years since, the

whole array of science and practice were brought to bear upon the elucidation of the cause. Undoubtedly the broken axle presented a crystalline fracture, but it has never been ascertained how far heat and magnetism were in operation, as in the case of an axle, and more especially a crank-axle, the constant vibration caused by irregularities in the way and the weight of the engine appears to be quite sufficient to occasion the breakage without aid from the other forces. Undoubtedly, in almost all cases of the sudden fracture of axles or wrought-iron bars, during employment, the fracture presents a crystalline structure; but we believe that any molecular disturbance, such as impact, can effect this, by breaking the fibre into a number of prisms, each of which, carefully examined, has the appearance of a crystal, the only question being, how long will the material sustain the action before it breaks? This question has been attempted to be decided by direct experiment under the direction of the Commission on Railway Structures. It was found that with cast-iron bars subjected to long continued impacts, "when the blow was powerful enough to bend the bars through one-half of their ultimate deflection (that is to say, the deflection which corresponds to their fracture by dead pressure), no bar was able to stand 4000 of such blows in succession. But all the bars (when sound) resisted the effects of 4000 blows, each bending them through one-third of their ultimate deflection. These results were confirmed by experiments with a revolving cam which deflected the bars.

"In wrought-iron bars, no very perceptible effect was produced by 10,000 successive deflections by means of a

revolving cam, each deflection being due to half the weight which, when applied statically, produced a large permanent flexture." These results agree with those obtained by my own experiments in regard to the effects of time on loaded bars of cast-iron already given.

Arago and Wollaston have paid considerable attention to this subject, the latter having been the first to point out that native iron is disposed to break in octohedra and tetrahedra, or combinations of these forms. The law which leads to fracture in wrought-iron from changes in the molecular structure, operates with more or less intensity in other bodies; repeated disturbances, in turn destroying the cohesive force of the material by which they are held together. A French writer of eminence, Arago, appears to consider the crystallisation of wrought-iron to be due to the joint action of time and vibration; but we think, with Mr Hood, that time and its duration depends entirely upon the intensity of the disturbing forces, and, moreover, that the time of fracture is retarded or accelerated in a given ratio to the intensity with which these forces are applied.

From the above statements we may safely deduce the fact, that it is essential to the use of this material to consider the purposes to which it is applied, the forms in which it may be moulded, and the conditions under which it may be placed, in order to arrive at just conclusions as to the proportions, in order to afford to the structure (whatever that may be), ample security in its powers of resistance to strain.

Tensile Strength.

On the subject of the strength of wrought-iron, there are my own researches, contained in a paper entitled, "An

Inquiry into the Strength of Wrought-iron Plates and their Riveted Joints, as applied to Shipbuilding and Vessels exposed to severe strain."* In that communication it is shown, from direct experiments, that in plates of rolled iron there is no material difference between those torn asunder in the direction of the fibre, and those torn asunder across the fibre. This uniformity of resistance arises probably from the way in which the plates are manufactured, which is generally out of flat bars, cut and piled upon each other, as at A (fig. 62), one-half transversely, and the other half longitudinally in the line of the pile. From this it will be seen that, in preparing the bloom or shingle for the rollers, the fibre is equally divided, and the only superiority that can possibly be attained is in the rolling which draws the shingle rather more in the direction of the length of the plate than in its breadth.

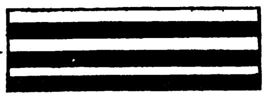
A


Fig. 62.

In the following table we have the results of the experiments:—

TABLE XVII.—*Tensile Strength of Wrought-iron Plates.*

Quality of Plates.	Mean Breaking Weight in the direction of the fibre, in tons per square inch.	Mean Breaking Weight across the fibre, in tons per square inch.
Yorkshire plates . . .	25·770	27·490
Yorkshire plates . . .	22·760	26·037
Derbyshire plates . .	21·680	18·650
Shropshire plates . .	22·826	22·000
Staffordshire plates . .	19·563	21·010
Mean	22·519	23·037

* Philosophical Transactions, part ii. 1850, p. 677. "Useful Information for Engineers," first series, Appendix 1.

Or as 22·5 : 23·0, equal to about $\frac{1}{46}$ in favour of those torn across the fibre.

From the above it is satisfactory to know, so far as regards uniformity in the strength of plates, that the liability to rupture is as great when drawn in one direction as in the other; and it is not improbable that the same properties would be exhibited, and the same resistance maintained, if the plates were drawn in any particular direction obliquely across the fibrous or laminated structure.

The following table contains a summary of the more recent experiments which I have made on the subject of the tensile strength of wrought-iron:—

TABLE XVIII.—*Tensile Strength of Wrought-Iron.*

Description of Iron.	Mean Breaking Weight in tons per square inch.		Ultimate Elongation.
	With Fibre.	Across Fibre.	
Lowmoor iron (sp. grav. 7·6885) . .	28·661	23·433	...
Lancashire boiler plates (9 specimens)	21·815	20·096	$\frac{1}{23}$ and $\frac{1}{35}$
Staffordshire iron	...	...	...
(Two ½-inch plates riveted together)	21·357		...
Charcoal bar iron	28·402	...	$\frac{1}{5}$
Best-best Staffordshire charcoal plate (Mean of 4 experiments) . . .	20·095	18·492	$\frac{1}{20}$ and $\frac{1}{23}$
Best-best Staffordshire plates (Mean of 4 experiments)	22·297	20·745	$\frac{1}{20}$ and $\frac{1}{26}$
Best-best Staffordshire plate . . .	26·706	24·474	$\frac{1}{15}$ and $\frac{1}{25}$
Best Staffordshire.	27·357	24·027	$\frac{1}{13}$ and $\frac{1}{22}$
Common Staffordshire	22·688	23·582	$\frac{1}{20}$ and $\frac{1}{23}$
Lowmoor rivet iron (Mean of 2 expers.)	26·801	....	$\frac{1}{4}$
Staffordshire rivet iron	26·563	...	$\frac{1}{4}$
Staffordshire rivet iron	26·646	...	$\frac{1}{5}$
Bar of the same rolled cold . . .	37·956	...	$\frac{1}{12}$
Staffordshire bridge iron	21·249	19·815	$\frac{1}{25}$ and $\frac{1}{35}$
Yorkshire bridge iron	22·290	19·616	$\frac{1}{25}$ and $\frac{1}{28}$

In the above table, where two ultimate elongations are

given, the first is that of the specimens broken with the strain in the direction of the fibre; the latter that of the specimens broken across the fibre. The mean ultimate elongation of Staffordshire bridge plates, from nine experiments by Mr Edwin Clarke, was $\frac{1}{37}$; for rivet iron, bearing a strain of 24 tons before breaking, $\frac{1}{8}$. Here in the above table we have for Staffordshire bridge plates a mean of $\frac{1}{30}$, and for Yorkshire plates $\frac{1}{26}$. In the rivet iron there is little or no difference between the Staffordshire and the Yorkshire, both of them bearing 26½ tons to the square inch, and ¼ of ultimate elongation.

From a previous inquiry we select the results of a series of experiments on the tensile strength of S C bars of different lengths, and about 1⅜ inches in diameter. The following tables give the strains required for each of four successive breakages of the same pieces of iron. These experiments are highly interesting, as they not only confirm those made upon plates, but they indicate a progressive increase of strength, notwithstanding the elongation and the reduced sectional area of the bars. These facts are of considerable value, as they distinctly show that a severe tensile strain is not seriously injurious to the bearing powers of wrought-iron, even when carried to the extent of four times repeated, as was done in these experiments. In practice, it may not be prudent to test bars and chains to their utmost limit of resistance; it is nevertheless satisfactory to know that in cases of emergency those limits may be approached without incurring serious risk of injury to the ultimate strength of the material.

The following abstract gives the results of the experiments:—

Length between the nippers.	Breaking Strain in tons.	Mean Elongation in inches.
Inches.		
120	32·21	26·0
42	32·125	9·8
36	32·35	8·8
24	32·00	6·2
10	32·29	4·2

"As all these experiments were made upon the same description of iron, it may be fairly inferred that the length of a bar does not in any way affect its strength."

Reduction of the above Table.

Length of Bar.	Elongation.	Elongation per unit of length.
Inches.		
120	26·0	·216
42	9·8	·233
36	8·8	·244
24	6·2	·258
10	4·2	·420

"Here it appears that the rate of elongation of bars of wrought-iron increases with the decrease of their length. Thus while a bar of 120 inches had an elongation of ·216 inch per unit of its length, a bar of ten inches has an elongation of ·42 inch per unit of its length, or nearly double what it is in the former case. The relation between the length of and its maximum elongation per unit, may be approximately expressed by the following formula, viz.,—

$$l = \cdot 18 + \frac{2\cdot 5}{L},$$

where L represents the length of the bar, and l the elongation per unit of the length of the bar."

The above results are not without value, as they exhibit the ductility of wrought-iron at a low temperature, as also the greatly increased strength it exhibits with a reduced sectional area under severe strain.

The following results were obtained on the tensile strength of wrought-iron produced by the Bessemer process at the Royal Arsenal, Woolwich, under the superintendence of Colonel Eardley Wilmot:—

TABLE XIX.—*Tensile Strength of Mr Bessemer's Iron in pounds per Square Inch.*

In its cast unhammered state.		Hammered or rolled.	
Various trials.	Mean.	Various trials.	Mean.
lbs. 38,197 41,584 43,290 40,234 42,908	41,242 lbs. = 18·412 tons.	lbs. 76,195 75,598 65,253 64,095 82,110	72,643 lbs. = 32·430 tons.

Flat Ingot rolled into Boiler Plate.

Various trials.	Mean.
lbs. 63,591 73,103 63,688 72,896	= 68,319 lbs. = 30·50 tons.

From the above will be observed the difference between the iron when compressed by the hammer or rolls and when taken in a state of ebullition from the converting furnace, while, although perfectly malleable, it is nevertheless in a crystalline state, the crystals probably requiring to be brought into more immediate contact by

impact or compression, as exhibited by the simple process of elongation under the mechanical influence of welding under the hammer or rolls. These processes, as may be seen, add one-half to the strength of the iron, the difference being in the ratio of 18 : 32.

Mr Clay gives the following interesting experiment on the effect of reheating and frequent rolling on the tenacity of wrought-iron. Taking a quantity of ordinary fibrous puddled iron, and reserving samples marked No. 1, he piled a portion five feet high, and heated and rolled the remainder into two bars, marked No. 2. Again reserving two samples from the centre of these bars, the remainder were piled as before, and so continued until a portion of the iron had undergone twelve workings. The following table shows the tensile strain which each bore:—

No. 1.	Puddled bar,	43,904 lbs.
2.	Reheated,	52,864 „
3.	„	59,585 „
4.	„	59,585 „
5.	„	57,344 „
6.	„	61,824 „
7.	„	59,585 „
8.	„	57,344 „
9.	„	57,344 „
10.	„	54,104 „
11.	„	51,968 „
12.	„	43,904 „

It will be seen from this that the quality of the metal improved up to the fifth reheating, and then decreased at the same rate.

The experiments are analogous to my own experiments on the process of remelting cast-iron, see page 194.

Resistance to Shearing.—With rivets and bolts, which fit accurately the holes in which they are placed, the resistance to shearing varies exactly as the sectional area of the material in the place of the rupture, and may be taken as 32,500 lbs. per square inch for cast-iron, and 50,000 lbs. per square inch for wrought-iron (Rankine).

Wrought-iron plates are united by riveted joints, in which the strength depends upon this form of resistance. The various forms of joints are known as lap-joints, in which one plate is lapped over the other and the rivets passed through each ; butt-joints and single riveted joints, in which the edges of the plates are made to abut against each other, and a covering strip, about four inches wide, is placed over the joint, and riveted to each of the plates; and lastly, chain-riveted joints, employed for the bottom of bridges, where it is essential to reduce as little as possible the strength of the parts, and therefore a covering strip of great length is employed (fig. 63), and the rivets are placed behind one another. The strength of the parts in riveted joints is reduced, in consequence of the parts punched out, in the proportion given in the following summary:—

Assuming for the strength of the plate . .	100
The strength of the double riveted joint will be	68
And that of the single riveted joint . .	46

Or for practice, allowing for the larger number of rivets in combination,*

* The general rule for proportioning riveted joints is, that the shearing area through the rivets should be equal to the area resisting tearing in the plate after deducting the rivet holes.

The strength of the plate being	100
That of a double riveted joint will be	70
And that of a single riveted joint	56

Or in pounds per square inch,

The strength of the plate being	50,000
The double riveted joint would be	35,000
And the single riveted joint	28,000

The great deficiency in the strength of joints subjected to a tensile strain caused considerable difficulty in designing the Britannia and Conway Bridges; double, treble, and quadruple riveting was thought of, but one after another was abandoned, on account of the rivet-holes weakening the plates; and I should almost have despaired of attaining the object in view, but for the system of longitudinal or chain riveting having occurred to me, after repeated trials of other modes and forms. Experiment, however, established the perfect security of this method, which is shown in fig. 63, where two lines of

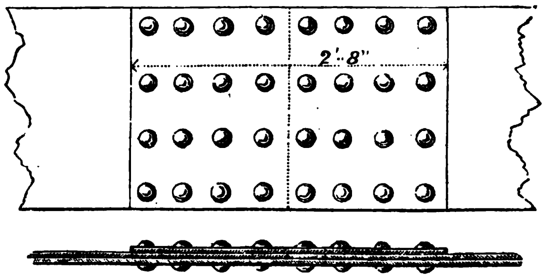


Fig. 63.

plate are supposed to be employed breaking joint, the joint in the upper one being covered by a strip 2 feet

8 inches long, secured by thirty-two rivets placed in rows.

The following is the result of an experiment on a joint of this form:—

Area of section through plates 2 × ·875 = 1·75 square inch.
Area of section through rivet-holes 1·5 " "
Rivets ½ inch diameter.
Broke with 69,664 lbs.
Equivalent to 17·77 tons per square inch.

Another experiment was made with a plate with two covering strips over the joint, fig. 64.

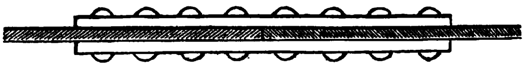


Fig. 64.

Area of section through solid plate, 3·5 × ·25 = ·875 square inch.
Area of section through rivet-holes, 3·0 × ·25 = ·750 " "
Diameter of rivets, ½ inch.
Broke with 41,002 lbs.
Equivalent to 20·92 tons per square inch, about the ultimate strength of the plate itself.

The defects of the riveted joint are so evident, that various attempts have been made to reduce their evils. At the commencement of the trade in iron shipbuilding I patented an arrangement for rolling plates with thick edges, and employed plates so prepared to some extent; but the cost of their production at that time, and some difficulties in their employment, prevented their general use. Mr Bertram has much more recently attempted to unite plates by welding, and with some success. The

joints so made are far stronger than the ordinary riveted joint, but their cost at present prevents their introduction. Mr Bertram scarfs the edges of the plates, places them together, and heats them by two pure gas flames ejected from nozzles, and produced by the ignition of coke or charcoal in a closed chamber by a regulated blast. Fig. 65 shows the way in which this is effected.

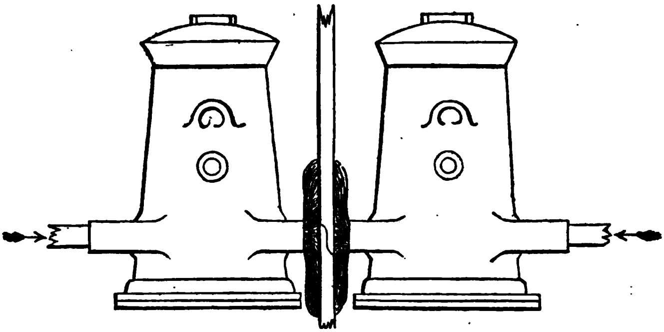


Fig. 65.

Resistance to Buckling or Bending from a Compressive Force.

Professor E. Hodgkinson has experimented upon this subject, and his results show that the resistance of plates of the same breadth and length varies as the cube of the thickness, or more nearly as the 2·878 power of it. Thus a plate double the thickness of another will resist flexure with seven or eight times the force applied in the direction of its length.

TABLE XX.—*Resistance of Plates of Wrought-iron to a force of Compression, the plates being in a vertical position, and well bedded against parallel and horizontal crushing surfaces.*

Length of plates.		Dimensions of section.	Weight of greatest resistance.	Weight per sq. inch of section, of greatest resistance.	Value of power of thickness deduced.
ft.	in.	in. in.	lbs.	tons.	
10	0	3·00 × 1·51	46,050	4·538	2·622
		3·01 × ·766	7,793	1·508	
10	0	3·00 × 1·51	46,050	4·538	3·073
		2·99 × ·995	12,735	1·911	
7	6	3·00 × 1·53	91,746	8·923	2·898
		2·983 × ·5023	3,614	1·076	
7	6	3·005 × ·9955	29,619	4·425	3·064
		2·983 × ·5023	3,614	1·076	
5	0	3·01 × ·995	54,114	8·066	2·735
		2·98 × ·507	8,469	2·502	
				Mean, . .	2·878

From this it would also appear, by a reduction of the results, that square bars of wrought-iron, long enough to be bent without being crushed, vary in strength as the 3·59th power of their lateral dimensions, or as $d^{3.59}$, where $d =$ the side of the square, the length being constant.

On the transverse strength of wrought-iron it will not be necessary to enlarge, as we have numerous examples before us in the experiments undertaken to determine the strength and form of the Britannia and Conway Tubular Bridges.* In these experiments will be found an entirely new description of form and construction, which have emanated from them, and which have led to a new era in the history of bridges, and the application

* See Mr Fairbairn's work on the Conway and Britannia Tubular Bridges.

of wrought-iron to other purposes besides those in connection with buildings, and its greatly extended application to the useful arts. For further information on this subject, I refer the reader to my own* and Professor Hodgkinson's works, in both of which will be found data sufficient to establish the great superiority of malleable over cast iron, or any other material, either as regards strength, or economy in its application.

On the resistance of wrought-iron plates to a force tending to burst them, Rondelet has shown that it requires a force of 70,000 lbs. per square inch to produce fracture, and my experiments proved that a wrought-iron plate of one quarter of an inch thick resisted a pressure from a ball 3 inches in diameter equal to that required to rupture a 3-inch oak plank.

STEEL.

The properties of steel have been much less perfectly investigated than those of wrought-iron. The following table shows its tensile strength :—

	lbs. per sq. inch.
Uchatius' cast-steel, ...	90,000
Ordinary cast-steel, ...	128,000
Krupp's steel gun, ...	129,000
Mersey puddled steel, . . .	94,752 (Mallet.)
Sheffield cast-steel, ...	130,000 (Rennie.)

The following table gives the results of some experiments under the direction of Colonel Wilmot at Woolwich on Mr Bessemer's steel :—

* "On the Application of Cast and Wrought Iron to Building Purposes," and "Useful Information for Engineers."

TABLE XXI.—*Tensile Strength of Mr Bessemer's Steel.*

In its cast, unhammered state.		Hammered or rolled.	
Various trials.	Mean.	Various trials.	Mean.
48,892 lbs.	45,836 lbs.	162,974 lbs.	154,825 lbs.
42,780		146,676	
57,295	68,259	158,899	157,881
79,233		156,862	
72,503	68,998	136,490	148,324
77,808		145,512	
61,667		162,970	
64,015			

These results give a mean of 27·246 tons for the unhammered, and 68·607 for the hammered or rolled steel, per square inch of section. Hence the same anomalous condition exists in the steel as was noticed in the Bessemer iron, where the effects of the hammer or rolls produced nearly double the strength. In the steel we have in the first experiment more than three times the strength, and in the mean of the whole as 61:154—more than double. This evidently shows how very important it is to have the material, whether of iron or steel, elongated and solidified under the hammer, or between the rolls, before it is used.

In the following table are collected the results obtained by myself on various descriptions of puddled steel and the so-called homogeneous metal :—

TABLE XXII.—*Experiments on the Tensile Strength of Steel.*

Description of material.	Breaking weight in tons per sq. in.	Ultimate elongation.
Homogeneous rolled steel (sp. gr. 7·8379)	41·510	
Rolled steel plate (hard) . . .	45·954	$\frac{1}{32}$
" " " (soft) . . .	38·129	$\frac{1}{32}$
Steel bar, puddled	40·196	
Steel plates, puddled, from Chesterfield (sp. gr. 7·8328)	41·800	$\frac{1}{8}$
Mr Mushet's gun-metal . . .	46·176	$\frac{1}{25}$

The above are very fair specimens of the manufacture by different makers, and give a pretty uniform result. They are however greatly inferior, as regards strength, to the results obtained from the Bessemer steel by Colonel Wilmot, which gave upwards of 68 tons per square inch.

CHAPTER XI.

THE CHEMICAL COMPOSITION OF IRON AND STEEL.

CAST-IRON is a carburet of the metal, of varying constitution, containing from 5 to 5·6 per cent. of carbon. Its fluidity and tenacity are considerably influenced by this circumstance, and the more so as the carbon exists in cast-iron in two conditions—viz., combined with the iron, or merely mechanically mixed with its crystals. Remelting the iron in the cupola, which, it has been seen, increases its tenacity, reduces the quantity of graphite or mechanically mixed carbon, and increases the proportion of combined carbon. In white cast-iron, the whole of the carbon is combined.

The following results were obtained by Mr Abel, of the Royal Arsenal, and communicated to the Chemical Society:—

Composition of Pig Iron smelted with Charcoal.

	Nova Scotia.			America.		
	Grey.	Mottled.	White.	Grey.	Mottled.	White.
Specific gravity	7·120	7·540	7·690	7·159	7·540	7·675
Iron	95·20	95·35	95·25	94·87	96·35	96·55
Combined carbon	...	1·72	2·96	·04	1·14	2·79
Graphite	3·11	1·38	...	3·07	1·50	...
Silicium	1·11	·26	·21	1·80	·79	·32
Sulphur	·01	·03	·02	trace.	·01	·06
Phosphorus	·13	1·30	1·53	·22	·20	·17
Manganese	·25	trace.	...	trace.	trace.	trace.
Copper	...	...	...	trace.	trace.	trace.
	Traces of titanium and cobalt.					

At the request of the British Association, Dr Thomson of Glasgow examined the chemical constitution of hot-blast iron, and he gives the following as the result of his inquiry:—

"(1.) The specific gravity of hot-blast iron is greater than that of cold-blast.

"The following are the specific gravities of eight specimens of cold-blast iron:—

1st, Muirkirk	6·410	5th, Muirkirk	6·7754
2d, Ditto	6·435	6th, From Pyrites	6·944
3d, Ditto	6·493	7th, From Carron	6·9888
4th, Ditto	6·579	8th, Clyde Iron-Works	7·0028

"The specific gravity of the Muirkirk iron is considerably less than of that smelted at Carron and the Clyde Iron-Works; the mean of the eight specimens is 6·7034.

"It has been hitherto supposed that the difference between cast-iron and malleable iron consists in the presence of carbon in the former, and its absence from the latter; in other words, that cast-iron is a carburet of iron. But in all the specimens of cast-iron which we analysed, we constantly found several other ingredients besides iron and carbon. Manganese is pretty generally present in minute quantity, though in one specimen it amounted to no less a quantity than 7 per cent.; its average amount is 2 per cent. *Silicon* is never wanting, though its amount is exceedingly variable; the average quantity is about 1⅛ per cent.; some specimens contained 3⅛ per cent. of it, while others contain less than a half per cent. Aluminum is very rarely altogether absent, though its amount is more variable than that of silicon. Its average amount

is 2 per cent.; sometimes it exceeds 4½ per cent., and sometimes it is not quite 1-5000th part of the weight of the iron.

"Calcium and magnesium are sometimes present, but very rarely, and the quantity does not much exceed 1-5th per cent. In a specimen of cast-iron which I got from Mr Neilson, and which he had smelted from pyrites, there was a trace of copper, showing that the pyrites employed was not quite free from copper; and in a specimen from the Clyde Iron-Works there was a trace of sulphur. The following table exhibits the composition of six different specimens of cast-iron No. 1, analysed in my laboratory, either by myself or by Mr John Tennent:—

	Muir-kirk.	Muir-kirk.	Muir-kirk.	Pyrites.	Carron.	Clyde.	Mean.
Iron	90·98	90·29	91·38	89·442	94·010	90·824	91·154
Copper	...	...	...	0·288	...	...	
Manganese	...	7·14	2·00	...	0·626	2·458	2·037
Sulphur	...	...	...	...	...	0·045	
Carbon	7·40	1·706	4·88	3·600	3·086	2·458	3·855
Silica	0·46	0·830	1·10	2·220	1·006	0·450	1·177
Aluminum	0·48	0·016	...	3·776	1·032	4·602	1·651
Calcium	...	0·018	0·20	...	...	...	
Magnesium	...	...	...	...	...	0·340	

"The constant constituents of cold-blast cast-iron No. 1, are iron, manganese, carbon, silicon, and aluminum. The occasional constituents are copper, sulphur, calcium, and magnesium. These occur so rarely, and in such minute quantity, that we may overlook them altogether.

"The constant constituents occur in the following mean atomic proportions:—

22 atoms iron	=77·00
½ atom manganese	= 1·75
4·36 atoms carbon	= 3·27
1 atom silicon	= 1·00
1⅛ aluminum	= 1·40—84·42

"(2.) I examined only one specimen of cast-iron No. 2. It was an old specimen, said to have come from Sweden; but I have no evidence of the correctness of this statement. Its specific gravity was 7·1633 higher than any specimens of cold-blast iron No. 1. Its constituents were,

Iron	93·594
Manganese	0·708
Carbon	3·080
Silicon	1·262
Aluminum	0·732
Sulphur	0·038—99·414

"The presence of sulphur in this specimen leads to the suspicion that it is not a Swedish specimen; for, as the Swedish ore is magnetic iron, and the fuel charcoal, the presence of sulphur in the iron is very unlikely.*

"In this specimen, the atoms of iron and manganese are to those of carbon, silicon, and aluminum, in the proportion of 4½ to 1, instead of 3½ to 1, as in cast-iron No. 1.

"The atoms of carbon, silicon, and aluminum, approach the proportions of 7, 2, and 1, so that in cast-iron No. 2, judging from one specimen, there is a greater proportion of carbon, compared with the silicon and aluminum, than in cast-iron No. 1.

"Mr Tennent analysed a specimen of hot-blast iron

* I have been told by Mr Mushet that the Swedes add sulphur to the iron No. 2.

No. 2, from Gartsherrie. Its specific gravity was 6·9156, and its constituents,

			Atoms.	
Iron	90·542	or	25·86	3·72
Manganese	2·764		0·78	
Carbon	3·094		4·05	1·
Silicon	0·680		0·68	
Aluminum	2·894		2·31	
Sulphur	0·023		0·011	
	99·997			

So that it resembles cast-iron No. 1 in the proportion of its constituents. The carbon is almost the same as in cold-blast iron No. 2; but the proportion of aluminum is four times as great, while the silicon is little more than half as much. The atomic ratios are, Carbon, 4; silicon, 0·67; aluminum, 2·28.

"(3.) Five specimens of hot-blast cast-iron No. 1 were analysed. Two of these were from Carron, and three from the Clyde Iron-Works, where the hot-blast originally began, and where, of course, it has been longest in use. The specific gravity of these specimens was found to be as follows:—

1st, From Clyde Works	7·0028
2d, From Carron	7·0721
3d, From Carron	7·0721
4th, From Clyde Works	7·1022
Mean, . . .	7·0623

"It appears from this, that the hot-blast increases the specific gravity of cast-iron by about 1-22d part. It approaches nearer the specific gravity of cast-iron No. 2, smelted by cold air, than to that of No. 1.

"The following table exhibits the constituents of these four specimens:—

	Clyde.	Carron.	Carron.	Clyde.	Clyde.
Iron	97·096	95·422	96·09	94·966	94·345
Manganese	0·332	0·336	0·41	0·160	3·120
Carbon	2·460	2·400	2·48	1·560	1·416
Silicon	0·280	1·820	1·49	1·322	0·520
Aluminum	0·385	0·488	0·26	1·374	0·599
Magnesium	...	...	...	0·792	...
	100·553	100·466	100·73	100·174	100·000

"The mean of these analyses gives us,

		Atoms.	
Iron	95·584 or	27·31	} 6·5
Manganese	0·871	0·249	
Carbon	2·099	2·79	} 1·
Silicon	1·086	1·086	
Aluminum	0·422	0·337	
	101·285		

Or in the proportion of 6½ atoms of iron and manganese to 1 atom of carbon, silicon, and aluminum. In the cold-blast cast-iron we have,

	Iron.	Carbon, &c.
In No. 1	3½ atoms	1 atom.
In No. 2	4½ „	1 „
In hot-blast	6½ „	1 „

"Thus it appears, that when iron is smelted by the hot-blast its specific gravity is increased, and it contains a greater proportion of iron, and a smaller proportion of carbon, silicon, and aluminum, than when smelted by the cold-blast."

As opening up a new field of observation in connection with the strength of cast-iron, we shall quote some of the general results from a very extensive series of analyses, made by order of the United States Government. These

analyses appear to have been made with extreme care, and the results, so far as they go, are satisfactory, and point to an explanation of some at least of the variations in the resisting powers of this material. We may premise that the guns of the United States Ordnance department are divided into three classes, according to the tests they have stood and the strength of the metal. A large number of specimens having been taken from guns of each class, were submitted to analysis by Mr Campbell Morfit and Mr J. C. Booth, and gave the following remarkably consistent average results :—

	Specific gravity.	Tensile strength.	Total carbon.	Combined carbon.	Allotropic carbon.
First-class guns,	7·204	28,805	·0384	·0178	·0206
Second-class guns,	7·154	24,767	·0376	·0146	·0230
Third-class guns,	7·087	20,148	·0365	·0082	·0283

The different effects produced by the *hot* and *cold* blast are clearly exhibited in the following table, both in reference to chemical composition and to specific gravity and tensile strength :—

Blast.	Specific gravity.	Tensile strength.	Total carbon.	Allotropic carbon.	Combined carbon.	Silicium.	Silicium and combined carbon.	Silicium and total carbon.	Slag.	Slag and allotropic carbon.
Hot,	7·065	19,640	·0869	·0292	·0076	·0159	·0235	·0528	·00487	·0341
Cold,	7·218	29,219	·0407	·0209	·0208	·0059	·0267	·0476	·00124	·0221

It will be observed that while there is a very great disproportion in the quantities of each *single* ingredient in the hot and cold blast metal, yet there is nearly the same amount of several combined, such as the slag and allotropic of carbon, the amount of silicium and combined

carbon, or silicium and total carbon. These numbers are significant; for although there is not a great disparity between the amounts of total carbon produced by hot and cold blast, yet the hot-blast has evidently driven off a portion of carbon from combination, so that the cold-blast contains two and three-fourth times as much combined carbon. The hot-blast metal, however, meets with some compensation for this loss of carbon by reducing by its intense heat a larger amount of silica, and assuming silicium.

The wide difference in the amounts of slag in the two metals is also remarkable.

The slag and allotropic (graphitic) carbon being of a brittle nature, and not united with the iron, coat the crystalline plates of the metal, and diminish their surface of contact; and consequently it follows that the tensile strength of the metal must decrease partly in proportion to the increase of slag and allotropic carbon.

CHAPTER XII.

THE STATISTICS OF THE IRON TRADE.

THIS work has already extended so much beyond the limits of our inquiry, that we must confine ourselves to an exceedingly brief notice of the statistics of this important manufacture. In 1740 the iron trade suffered a sudden check from a falling off in the supply of charcoal, coal or coke not having been employed at that time for smelting. The annual production seems to have decreased from 180,000 to about 17,350 tons per annum. This comparatively small quantity was smelted in the following counties, viz.:—

	Furnaces.	Tons.		Furnaces.	Tons.
Brecon . .	2	600	Nottingham .	1	200
Glamorgan .	2	400	Salop . .	6	2000
Carmarthen .	1	100	Stafford . .	2	1000
Cheshire . .	3	1700	Worcester .	2	700
Denbigh . .	2	550	Sussex . .	10	1400
Gloucester .	6	2850	Warwick . .	2	700
Hereford .	3	1350	York . .	6	1400
Hampshire .	1	200	Derby . .	4	800
Kent . .	4	400		—	———
Monmouth .	2	900		59	17,350

	Tons	cwt.	qrs.
Annual average for each furnace . .	294	1	1
Weekly ,, ,, . .	5	13	0

Soon afterwards the difficulties in the way of using coal were overcome, and the manufacture extended rapidly.

The number of charcoal furnaces decreased, but the quantity produced by each was considerably increased. The following table shows the state of the trade in 1788:—

	Charcoal.			Coke.		
	Furnaces.	Tons each.	Total.	Furnaces.	Tons each.	Total.
Gloucester	4	650	2600			
Monmouth . . .	3	700	2100			
Glamorgan . . .	3	600	1800	6	1100	6,600
Carmarthen . . .	1	400	400			
Merioneth	1	400	400			
Shropshire	3	600	1800	21	1100	23,100
Derby	1	300	300	7	600	4,200
York	1	600	600	6	750	4,500
Westmoreland . .	1	400	400			
Cumberland	1	300	300	1	700	700
Lancashire	3	700	2100			
Sussex	2	150	300			
Stafford	...	...	...	6	750	4,500
Cheshire	...	...	...	1	600	600
Brecon	...	...	...	2	800	1,600
Stafford (about to blow)	...	...	...	3	800	2,400
	24	...	13,100	53	...	48,200

	Charcoal.			*Coke.*		
	Tons	cwt.	qrs.	Tons	cwt.	qrs.
Annual average from each furnace .	545	16	2	907	0	0
Weekly „ „ .	10	9	3	17	9	0

In the same year were erected and blowing in Scotland the following furnaces:—

	Charcoal.			Coke.		
	Furnaces.	Tons each.	Total.	Furnaces.	Tons each	Total.
Goatfield	1	700	700			
Bunawe	1	700	700			
Carron	...	...	...	4	1000	4000
Wilsontown . . .	...	...	...	2	800	1600
	2	...	1400	6	...	5600

Total quantity of charcoal iron in Britain in 1788	.	14,500
Do. coke do. do.	.	53,800
Total quantity of iron in Britain in 1788	. .	68,300
Do. do. 1740	. .	17,350
Increased produce of pig iron	. .	50,950

About the year 1796 it was contemplated by Mr Pitt to add to the revenue by a tax on coal. This met with a powerful opposition on the part of the manufacturers and consumers, especially those in the iron trade. A committee was appointed, witnesses were examined, and the measure abandoned as unwise and impracticable. The following table exhibits an abstract of the facts collected, and shows the rapid progress of the iron trade in the eight preceding years:—

Counties.	No. of Furnaces.	Excise Return of Iron made.	Supposed quantity by the Trade.	Actual Return.
Chester	2	4,710	2,200	1,958½
Cumberland	4	5,144	3,000	2,034
Derby	3	2,138	2,138	2,107
Gloucester	2	380	380	380
Hereford	5	2,850	2,850	2,529
York	22	21,984	21,987	17,947
Shropshire	23	68,129	43,360	32,969
Wales	28	45,994	42,606	35,485
Stafford	14	15,820	15,256	13,210½
Sussex	1	172¾	173	173
	104	167,321¾	133,950	108,793

	Tons.
The return from Scotland exhibited a list of 17 furnaces, and an exact return of pig iron, manufactured, of	16,086
Making an annual total of	124,879
Annual average produce from each furnace, including charcoal furnaces	1,032
Increase of annual average since 1788	232

The following table shows the comparative make of pig iron in 1820 and 1827:—

	1820. Tons.	Furnaces.	1827. Tons.
North Wales	150,000	12	24,000
South Wales		90	272,000
Shropshire	180,000	31	78,000
Staffordshire		95	216,000
Yorkshire	50,000	24	43,000
Derbyshire		14	20,500
Scotland	20,000	18	36,000
	400,000	284	690,500

From that time to the present the manufacture has steadily increased. The following tables give the state of the trade in 1854–57; the particulars are extracted from the Mining Records, published under the direction of Mr R. Hunt, in connection with the Museum of Practical Geology, London. The importance which Scotland has assumed in reference to the iron manufacture is especially worthy of notice.

Counties.	No. of Works.	No. of Furnaces erected.	No. of Furnaces in blast.	Total produce in tons.
ENGLAND :—				
Northumberland, Durham, and Yorkshire	37	106	80	348,444
Derbyshire	13	33	25	127,500
Lancashire and Cumberland	2	5	3	20,000
Staffordshire	72	203	166	247,600
Shropshire	13	34	28	124,800
Gloucestershire	4	7	5	21,990
WALES :—				
Flintshire, Denbighshire	7	11	9	32,900
Glamorganshire, Anthracite district	14	35	21	750,000
Glamorganshire and Monmouthshire—Bituminous district	34	134	100	
SCOTLAND :—				
Ayrshire	9	41	30	249,600
Lanarkshire	13	88	72	468,000
Other Counties	10	27	16	79,040
	228	724	555	3,069,874

Total Produce of Pig-Iron in Great Britain in 1857.

	Tons.
ENGLAND—	
Northumberland	63,250
Durham	284,500
Yorkshire	296,838
Lancashire	1,233
Cumberland	30,515
Derbyshire	112,160
Shropshire	117,141
North Staffordshire	134,057
South Staffordshire and Worcestershire	657,295
Northamptonshire	11,500
Gloucestershire	23,882
Somersetshire	300
WALES, North	37,049
„ South, Anthracite Districts	63,440
„ South, Bituminous Districts	907,287
SCOTLAND	918,000
IRELAND	1,000
Total Produce in Great Britain and Ireland,	3,659,447

The quantity of iron ore raised in all parts of the United Kingdom in 1857, and used in the production of pig-iron, was found from the same returns to be 9,573,281 tons.

For smelting which there were in active operation in

England	333	blast-furnaces.
Wales	170	„
Scotland	124	„
Ireland	1	„
	628	

The mean average price of the pig-iron "mixed numbers," deduced from all the sales of the year, was L.3, 10s. 2d., which gives the market value of the pig-iron made as L.12,838,560 per annum. If we assume that the make of iron has increased in the same rate since 1857, it must now amount to 4,250,000 tons.

In connection with the above, we insert the following table from Mr Kenyon Blackwell's paper on the Iron Industry of Great Britain, read before the Society of Arts. It gives the estimated production of crude iron in the various countries.

	Tons.		Tons.
Great Britain . .	3,000,000	Russia . . .	200,000
France . . .	750,000	Sweden . . .	150,000
United States . .	750,000	Various German States	100,000
Prussia . . .	300,000	Other Countries .	300,000
Austria . . .	250,000		
Belgium . . .	200,000		6,000,000

The following table gives the annual production of steel in various countries:—

England—Cast steel	23,000	tons.
Bar steel	7,000	„
Spring steel	10,000	„
Total . . .	40,000	„
France	15,000	„
Prussia	5,453	„
Austria	13,037	„
United States	10,000	„

In referring to the above, it will be seen that Great Britain produces as much crude iron as all other countries put together; and a great portion of that iron being converted into bars and plates, indicates a large and important article of production,—an article of immense value to the country—of great demand at home and abroad—and justly entitled not only to improvements and economy in its manufacture, but to the generous support of a liberal and an enlightened Government.

APPENDIX.

ARMOUR-PLATED SHIPS.

In the foregoing Treatise I have endeavoured to lay before the reader, in as practical a manner as possible, the present state of our iron manufacture; but this would now be imperfect if we did not notice some great changes in prospect in its application. We have already recorded the many uses to which iron is applied, and the many improvements which have been effected to meet the requirements of construction. Of late years these requirements have increased in a high ratio, and there is scarcely any of the industrial arts to which it is not necessary. To the advancement of the arts it has probably contributed more than all the rest of the mineral kingdom—coal only excepted—put together. Its ductility, tenacity, and plastic character render it convertible into every form; and its powers of resistance to strain are so great as to supersede in construction every other description of material. This being the case, it is not surprising that iron should be found a perfect and durable material for shipbuilding. I was amongst the first to make this discovery; and since 1830 the extension of the use of iron in this branch of industry has been steady and progressive.

Attempts were made at an early period by the Govern-

ment to introduce iron in ships of war; but, owing to the imperfect state of our knowledge, and the prejudices of old admirals and officials, the material was condemned, and the wooden walls remained triumphant against all innovation. This was excusable to a great extent, as experiments which were at that time instituted for the purpose of ascertaining the resistance of iron plates to projectiles were highly discouraging, and the service generally was only too glad to avail itself of these failures in preventing the use of iron. In this state the question remained for the last twenty years; and but for the superior sagacity of the Emperor of the French, we might have continued to build with an inferior material for a much greater length of time.

The construction of the "Gloire" with armour-plates has, however, settled the question of *wood* versus *iron;* and there no longer exists a doubt as to the superior advantages and impregnable character of the iron ship. The "Warrior," "Black Prince," and other vessels of a similar description, are striking examples of the superiority of the iron-cased ship; and although far from perfect, they are nevertheless of a class that must eventually supersede our wooden navy.

In my opinion, the whole navy of Great Britain must be remodelled and rebuilt of iron; and no administration in this country should venture to place another wooden vessel on the stocks. I further believe that it is not only necessary to provide an iron armour, but that the whole structure should be composed of iron, and sheathed with thick plated fenders from the upper deck down to a depth sufficient to protect the ship below the

water-line. This, with an iron, bomb-proof upper deck, will render the ship invulnerable to the heaviest shot, and secure in every circumstance in which she can be assailed either by sea or from the land.

Having stated this much, I would direct attention to a new and important branch of manufacture, which in all probability will shortly come into existence, and that is the production of wrought iron in very large masses. It is not yet determined in what form these uses will be required, but I have considered it my duty in this place to direct attention to the subject, in order that the iron-masters of this country may be prepared to meet a large demand at a comparatively cheap rate.

It is known that a Committee on this subject is now sitting, and it may be expected that a series of facts derived from actual experiment will satisfactorily determine the form and conditions under which these plates must be applied. It would be premature to offer any opinion on this difficult question, or to attempt to anticipate the collective wisdom of the Committee. Suffice it to observe, that the members are men of experience, who will take a sound practical view of the subject, and recommend no change but what is conducive to the security and best interests of the country.

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THE END.

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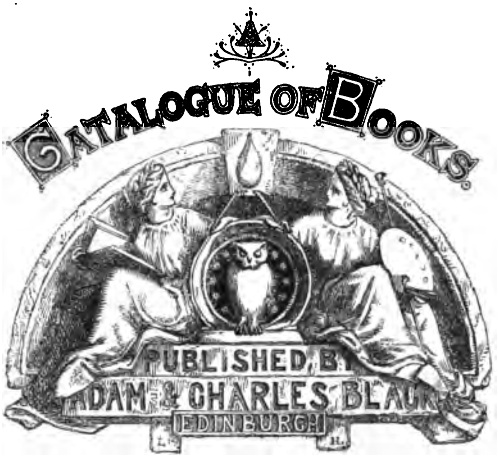

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